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JOURNAL

OF THE

AMERICAN WELDING SOCIETY

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Volume 5 **MARCH, 1926** **Number 3**

TABLE OF CONTENTS

Society and Related Activities

Program Annual Meeting 3
Welded Rail Joint Activities 5
American Bureau of Welding 6
Pressure Vessels 6
Annual Meeting 6
Section Activities 6
Employment Service Bulletin 7

Technical Papers, Items and Reports

The Metallurgy of an Arc Weld in Mild Steel 8
Metallurgy of Welds 16
Reclaiming Locomotive Main Rods 19
Oxy-Acetylene Welding of Copper 23
Welding and Cutting Die Parts 31
Automatic Hydrogen Arc Welding 32
Arc Welding in Hydrogen and Other Gases 46
Electro-Gas Under Water Cutting 55
Current Welding Literature 57

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AMERICAN WELDING SOCIETY
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JOURNAL

Volume 5 MARCH, 1926 Number 3

PROGRAM

ANNUAL MEETING

of the

AMERICAN WELDING SOCIETY

29 West 39th Street, New York, N. Y.

April 21, 22 and 23, 1926

All Sessions Start Promptly as Scheduled

WEDNESDAY, APRIL 21, 1926

Morning

Gas Welding Committee, S. W. Miller, Chairman
9:30 a. m. to 12, Rcom 1101.

A review of progress made by various sub-committees, including those on materials for welding, welds subjected to high temperature and training of operators.

Afternoon

Electric Arc Welding Committee, H. M. Hobart, Chairman
2:00 p. m. to 5, Room 1101.

Discussion of reports of Sub-Committee on Non-Ferrous Metals and Fundamentals of Arc Welding. A large number of additional tests have been made during the past year on specimens welded to determine the effect of such factors as current, size of electrodes, design of joints, positions of welding, etc. Consideration will also be given to the possibilities of a scientific investigation on the fundamentals of arc welding, including a review of welding under hydrogen atmosphere.

THURSDAY, APRIL 22, 1926

Morning

Business Session of the American Welding Society
9:15 a. m. to 11, Room 1.

1. President's Report of Year's Activities.
2. Financial Report.
3. Election of Officers.

Note: Business has been condensed in order to allow greater time for the technical sessions which follow.

Thursday, April 22 (Continued)

Technical Session

11 a. m. to 12:30 p. m., Room 1.

Design of Welded Equipment for Chemical Plants. Mr. H. D. Edwards, Works Manager, Carbide and Carbon Chemical Corporation.

Luncheon

12:30 to 2.

Note: It is planned to arrange a luncheon for members of the Society at the Engineers Club. Reservations should be made in advance.

Afternoon

Technical Session

2:00 p. m. to 5 p. m.

1. Design of Joints in Piping Installations. L. J. Sforzini.
2. Design of Joints in Ship Construction. J. W. Owens, Director of Welding, Newport News Shipbuilding and Dry Dock Co.
3. Design of Welded Joints With Special Reference to Pressure Vessels. S. W. Miller, Consulting Engineer, Union Carbide and Carbon Research Laboratories.
4. The design of an Arc-Welded Pressure Vessel. L. H. Burkhart, Chief Engineer Struthers-Wells Co.
5. Design of Welded Joints for Tanks and Containers. A. C. Vick, Engineering Dept., Detroit Range, Boiler & Steel Barrel Co.

Note: The technical papers are planned to form a symposium on the subject of design of welded joints in several industries covering: (a) Stresses—kinds and amounts; (b) Accessibility and position; (c) Technique; (d) Type of joints; (e) Materials; (f) Thermal considerations; (g) Tightness; (h) Tests.

Evening

Dinner Dance

6:30 p. m.

It is planned to make the annual dinner of the American Welding Society, which in the past has been enjoyed by all the members, a function to which ladies will be invited. Although all the details have not been decided as yet, pending financial arrangements, plans include an annual banquet with very short addresses of incoming and outgoing Presidents, a popular scientific talk on what science means in our every day life and an interesting demonstration of the wonders of liquid oxygen. As an example of the latter, we will see among other things mercury frozen so hard that it can be used as a hammer to drive nails, a rubber ball frozen so stiff that it will crack like glass from the blow of a hammer, and an egg boiled hard and then changed back again. Professional entertainment and a dance will follow these exhibitions. Reservations should be made in advance by applying to the Secretary.

FRIDAY, APRIL 23, 1926

Morning

Meeting of the American Bureau of Welding

9:30 a. m. to 12, Room 903.

The possibilities of pure scientific and practical research in welding will be fully demonstrated at the annual meeting of the American Bureau of Welding. Selected experts will give brief five minute discussions of suggested researches with an indication of how the problems might be solved and the possibilities of the results to be obtained. The business will also include a review of progress by sub-committee chairmen, plans for new work and election of officers. All the executives of outstanding corporations interested in welding will be invited to this meeting.

Afternoon

2:00 p. m. to 5.

Inspection trip to the Metal and Thermit Corporation.

Members will be transported from Journal Square, Jersey City, by buses provided by the Metal and Thermit Corporation. At the plant will be shown the making of thermit, how it is used in various kinds of welding operations, including welding heavy sections of iron and steel and welding of rails and pipes.

Note: Members may proceed via Hudson Tube to Journal Square. Buses will start promptly from Journal Square at 2 p. m.

Board of Directors, American Welding Society (including retiring and new members)

2:00 p. m. to 5, Room 1101.

(a) A review of progress during the year.
(b) Introduction of new President.
(c) Appointment of Committees.
(d) Plans for coming year.

WELDED RAIL JOINT ACTIVITIES

Keen interest was displayed by members of the Executive Committee of the Committee on Welded Rail Joints at their recent meeting in Washington on February 12 in a proposed program to measure stresses in rail joints under various conditions. The program proposes to make use of an electrical recording strain gage device called the "Telemeter," which has been perfected by the Bureau of Standards. Stresses will be measured in various parts of the joints caused by a trolley car dropping from different heights of a shim placed on a track. Stresses will also be measured under the same conditions with bolted and other types of welded joints other than the seam and some joints will only have the top seams welded and others only the bottom seams. Another phase of this type of investigation will involve the measurement of stresses of joints under the repeated impact testing machine with various methods of supports and different heights of drop of the weight.

A series of tests were made to determine what welding wire shall be used in the remaining investigations planned by the Committee seeking to improve the seam welded type of joint. It was impossible to select welding wires as a result of these tests because other variables, notably the personal equation, masked the results.

Preceding the meeting, a day was devoted to the examination of the joints broken by the repeated impact testing machine. Results of the re-

peated impact tests will be published shortly in Progress Report No. 4 of the Welded Rail Joint Committee.

It is planned to start very shortly with the welding of different types of joint plates in order to develop a top seam which will have the maximum cross section of soundly fused weld metal.

AMERICAN BUREAU OF WELDING

The annual meeting of the American Bureau of Welding will be held in conjunction with the annual meeting of the American Welding Society on Friday morning, April 23. In addition to the customary reports of progress of research sub-committees and the election of officers, the major portion of the time will be given over to five minute addresses by several selected experts on some welding problems needing solution, suggested methods of investigation and the probable value of such scientific and practical research. Prominent executives of the corporations interested in the art of welding will be invited as guests. It is hoped that in this way the Bureau will be enabled to undertake investigations amounting to many thousands of dollars which will materially advance the welding industry.

PRESSURE VESSELS

Rapid strides are being made in the planning of a thorough, comprehensive, scientific investigation in the field of pressure vessels in collaboration with the A. S. M. E. and other interested scientific and technical organizations. Scientific and practical tests will be made to secure fundamental information which will be of the greatest value to designers of pressure vessels and which will aid the A. S. M. E. Boiler Code and other legislative bodies in framing proper codes and regulations for the construction and use of such vessels. With the aid of National Research Council the best scientific talent available will be placed at the disposal of the Committee for studying the many intricate problems involved.

ANNUAL MEETING

The next annual meeting of the Society will be held on April 21 to 23. Many organizations realize the advantage of having interested members on their forces attend the meetings of a professional society such as our own.

The advantages of such attendance are many fold, and one of the most important which is often times lost sight of, is the opportunity of informal discussion of technical men with two or three other workers in the same field.

A broader viewpoint, greater enthusiasm, development of personality that comes from such attendance, is of primary importance.

Moreover, members gain important technical knowledge from the reading and discussion of papers, inspection trips and social functions.

In a young industry such as our own these annual affairs are one of the greatest factors in boosting the industry and extending it in new fields. Research committee meetings serve to keep interested members informed of the latest developments in the art and the direction in which further progress will be made.

SECTION ACTIVITIES

Chicago

The February meeting of this Section was held on the 5th in the rooms of the Western Society of Engineers. Mr. George A. Ellinger of the Page Steel & Wire Co., Monessen, Pa., was to present a paper on "Metallurgy of Welds." Unfortunately, Mr. Ellinger was unable to be present and his paper was read by the Secretary. A two-reel motion picture loaned by the Chicago Steel & Wire Co., "From Mine to Welding Rod," was also shown.

Pittsburgh

About 150 people attended the Feb. 12 meeting of this Section, when Mr. S. W. Miller presented his paper on "The Oxy-Acetylene Welding of Copper."

Los Angiees

The February meeting was held on the 11th. Mr. J. F. Lincoln presented a paper on "Use of the Arc Welder as a Manufacturing Tool. Mr. W. H. Stoody spoke on the methods of arc welding as applying to weld oil tools. Mr. Vernon Simmons spoke on methods

of welding aluminum. Other discussions centered around the application of welding in the structural field and the training of operators.

Cleveland

The February meeting of this Section was held as a joint meeting with the Society of Industrial Engineers. A liquid air demonstration was given by Mr. G. E. Harcke of the Air Reduction Sales Co. Following this, Mr. Harcke presented a four-reel film entitled "Oxygen, the Wonder Worker," accompanied by a most interesting lecture. About one hundred persons were in attendance.

Philadelphia

On Feb. 15 Mr. W. A. Gibb of the Gibb Instrument Co. gave an excellent talk on "Seam and Roller Welding." Mr. H. M. Hobart, consulting engineer, General Electric Co., will present an address on "Automatic Arc Welding and Its Benefits to the Welding Art" at the March meeting.

San Francisco

The February meeting of this Section was held on the 19th, at which Mr. J. F. Lincoln of the Lincoln Electric Co. delivered a paper on "Some Recent Developments in Arc Welding."

Northern New York

This Section held its February meeting on the 24th. Mr. J. B. Green, president, Chicago Steel & Wire Co., presented a paper on "The Effect of Flux Coatings on the Mechanism of the Metallic Arc."

Portland

Plans are under way for the organization of a Portland Section of the American Welding Society. Local members are keenly enthusiastic and there is every reason to believe that a local section will be started in the very near future.

New York

A very interesting meeting was held on March 8. Mr. S. W. Miller, consulting engineer of Union Carbide and Carbon Research Laboratories, gave a very interesting talk on "Oxy-Acetylene Welding of Copper." Mr. N. T. Chute of the Lincoln Electric Co. presented a paper on "Fabrication and Erection by the Electric Arc Welding Method of a Crane Runway 245 feet long at the Coplay Cement Manufacturing Co., Coplay, Pa."

EMPLOYMENT SERVICE BULLETIN

POSITIONS VACANT

V-31. Salesmen and Estimator wanted. Required by one of the largest and best established job welding concerns in New York. Preferably a man who has experience or one who has a fair knowledge of welding, both gas and arc, and who is accustomed to doing business with large service stations and fleet owners.

An interesting proposition will be made to the right man, which assures a good income on a salary and commission basis, to a live wire who can produce. All details will be treated in confidence.

V-32. Experienced welder or welding engineer wanted who has had broad experience in tank welding including bath boiler construction. In our Seamless Division we have decided to develop welding of certain types and styles of containers, and we want experienced man to follow work through various stages including testing.

Services Available

A-41. Electric welder desires position. Have had 8 years' experience, including repair, machine and boiler work on the Erie R. R. and high pressure vessel and tank work of Standard Oil Co.

A-42. Electric welder desires position. Have had 10 years' experience, including six with the Tide Water Oil Co., three years with Standard Oil and one and one-half years with M. W. Kellogg Co.

A-43. Oxy-acetylene welder desires position. Have had five years' experience and can weld any kind of work, including aluminum.

A-44. Acetylene welder desires position. Have had seven years' railroad shop welding experience and four years' industrial welding. Desire position as Foreman or Supervisor. Have credentials as welder, also as instructor.

A-45. Oxy-acetylene welder desires position. Have had experience and can furnish reference.

The Metallurgy of an Electric-Arc Weld in Mild Steel

By A. G. BISSELL†

Probably the most interesting side of electric arc welding is the metallurgical phase. The casual observer no doubt is more impressed by the electrical than the metallurgical phenomenon. This is due, of course, to the brilliant light of the arc, the connecting wires and the electrical equipment near at hand. Few if any have any conception of the complicated metallurgical changes that are occurring in the immediate vicinity of the arc.

First, for the benefit of those who are not familiar with the process of electric arc welding, let us consider its elementary principles. Let us consider the disposition of the metal of a mild steel, welding wire onto a steel plate, following through the process, step by step.

The power used is either direct or alternating current, supplied by a special generator or transformer. In the case of direct current the positive side of the circuit is connected to the plate upon which the deposit is to be made. The negative side of the line is connected by means of a special holder to a steel wire. The steel wire is brought in contact with the steel plate, then parted from it a distance of about an eighth of an inch; an arc results that produces a temperature of between 2000 and 2500 deg. C. This intense heat localized at the point of impact of the arc stream immediately fuses a spot on the plate into which the molten metal from the end of the wire is projected. This molten metal from the wire unites with the molten metal of the plate to build up a deposite that solidifies as the arc proceeds. In this manner metal may be built upon a surface or it may be deposited between the edges of two plates in such a way that they are solidly and completely united.

Now let us see what happens to our metals. Our electrode wire is of hard-drawn mild steel having the following average chemical composition:

Carbon, 0.16 per cent; manganese, 0.56 per cent; phosphorous, 0.032 per cent; sulphur, 0.024 per cent; silicon, 0.016 per cent.

Tensile strength, 100,000 lbs. per sq. in.; elongation, 5 per cent in 2 in.

The reason that this wire has such a high tensile strength is because it is hard drawn, and we find that a hard-drawn wire gives the most satisfactory results. It is quite an advantage to use hard-drawn wire because it will pass through the arc much better and penetrate better than an annealed wire. The reason for this, I do not know. It seems that, especially in welding overhead, the globule of metal that forms at the end of the wire will run down

†General Engineer, Westinghouse Electric & Manufacturing Co.

on the annealed wire, while on a hard-drawn wire it will stay in place and is easily put in an overhead weld.

In passing through the arc, this metal in the molten and vapor-

Fig. 1. Showing Structural Changes In a One-Layer Continuous Weld Made in a ½-inch, Mild Steel Plate

ized states comes in contact with the elements of the air at the external surface of the arc stream; the extent of this contact being determined by the length of the arc held by the operator. The shorter the arc, the less the metal is affected by the atmospheric

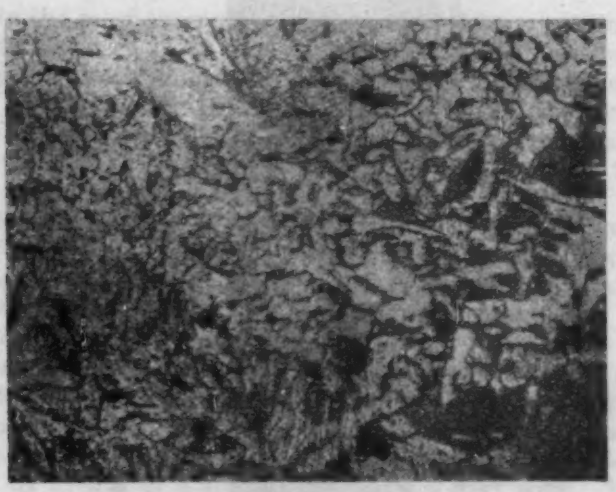

Fig. 2. In Which Is Shown the Intimate Union Between the Added Metal and Plate

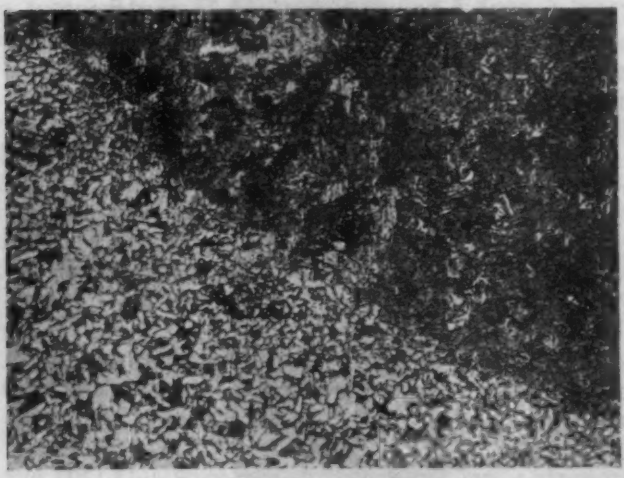

Fig. 3. Showing Structure of Arc-Weld Joint Where Metal is Deposited in Strings of Beads

elements. At the temperature of the arc the main elements of the air, oxygen and nitrogen have a great affinity for the metals in the arc stream. The result of this affinity is that the nitrogen and oxygen combine with the elements of the wire to form oxides and nitrides. The carbon of the wire combines with the oxygen

of the air to form carbon dioxide and carbon monoxide. Both of these compounds are gases and escape; that is, unless they are entrapped in the molten metal. The oxides of iron, manganese and silicon float to the surface of the molten metal as slag. The

Fig. 4. Illustrating the Resulting Structure Obtained by Furnace Annealing

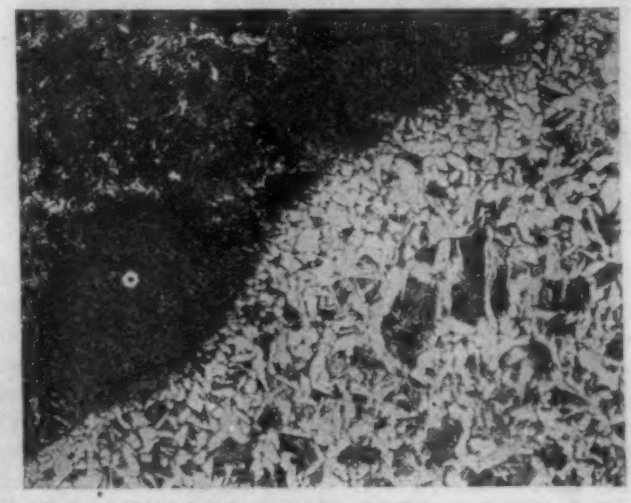

Fig. 5. Section of Weld Made by Use of Excessive Current

phosphorus and sulfur are altered but little. The nitrogen combines mainly with the iron. To be sure, some of each of the oxides and nitrides are scattered throughout the metal, but the extent of this is determined by the amount that is permitted to enter by the operator. An analysis of the above metal after passing through the arc is given as: carbon, 0.05 per cent; manganese, 0.18 per

cent; phosphorus, 0.031 per cent; sulfur, 0.036 per cent; silicon, 0.011 per cent; nitrogen, 0.11 to 0.13 per cent; oxygen, 0.25 to 0.55 per cent; tensile strength, 55,000 to 62,000 lb. per sq. in. To prevent the introduction of impurities into the metal that is being deposited, is to make a good weld. By holding a very close arc, that

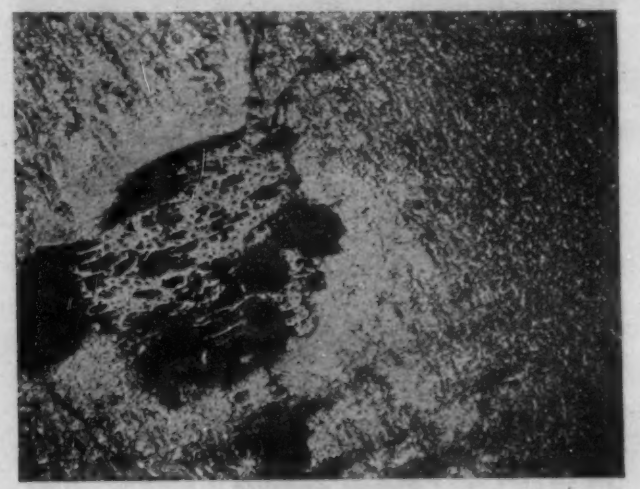

Fig. 6. An Oxide Inclusion Resulting from Poor Operation

Fig. 7. Structure of Brittle Metal Produced by Heating to 760° C. and Then Cooling

is, between one-eighth and three-sixteenths of an inch, the arc stream is completely surrounded by an envelope, mainly of iron-oxide vapor that prevents the active oxygen and nitrogen on the outside from coming in contact with the active elements on the inside and permits a fairly pure metal to be deposited on the work.

Now that we have passed the metal through the arc into the

molten spot on the plate and again solidified it, let us see what we have. By melting the steel wire and again solidifying it, we have produced cast steel and at the same time altered the crystalline structure of the plate metal in the immediate vicinity of the deposit.

The first photomicrograph (Fig. 1) shows a section of the metals extending from the added metal through the line of fusion into the plate in a one-layer continuous weld. The actual section shown is 0.026 in. x 0.165 in. on the specimen. To those who are familiar with the microstructure of steel, it is evident that the light metal at the left is of a cast structure. This is the deposited metal and consists of iron of the analysis given above. This structure blends into a different structure a little to the right. This is the line of

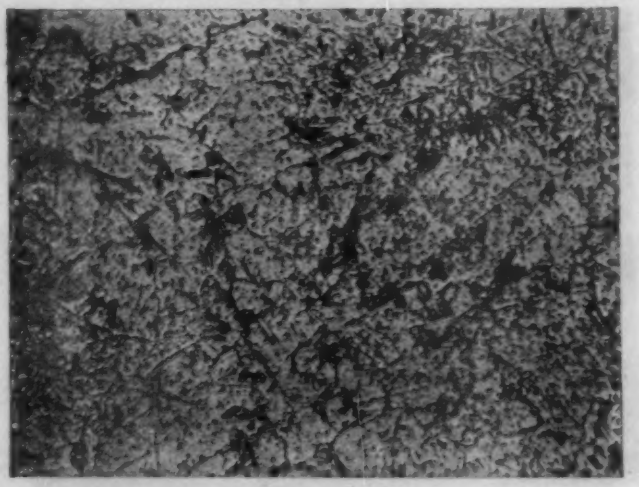

Fig. 8. Structure of Deposited Metal Obtained by Using Too High a Current

fusion between the plate metal and the deposited metal. This coarse structure is typical of a steel (0.20 per cent carbon) that has been heated to a temperature over 1000 deg. C. Where the two structures blend, fusion occurred at about 1300 to 1400 deg. C. The heat conducted through the plate away from the line of fusion produces structures corresponding to the temperatures reached. The dark, coarse structure just to the right of the line of fusion is characteristic of an overheated steel. It is brittle. This material extends about 0.015 in. into the plate. As we proceed further into the plate the grains grow smaller until the minimum size is reached at the point where true annealing occurred. Here the temperature reached about 780 deg. C., or just above the critical point of the steel. The material at this point has a tensile strength of about 60,000 lb. per sq. in. and an elongation of about 25 to 30 per cent in 2 in. Further on the structure again coarsens, blending into the original structure of the plate. This picture is interesting for

the fact that it shows all the structures obtainable by heat treating a mild steel between its critical point and its melting point.

The intimate union between the added metal and the plate is clearly shown in Fig. 2. It can be seen that the crystals of each metal are perfectly immeshed. The added metal may be identified by the inclusions of oxide and nitride that appear as black specks in it. The added metal in this particular specimen developed a tensile strength of 57,100 lb. per sq. in. and an elongation of 8.5 per cent in 1 in. The test piece was bent at the weld to 39 deg. before fracture occurred.

It is not necessary, however, to allow this varied structure to remain in your work. An arc weld need not be a casting, nor is

Fig. 3. Arc-Deposited Metal That Is Clean and Free from Impurities

it necessary to anneal the work to prevent it, as some appear to believe. On metal 3/8-in. thick or heavier, an arc-weld joint may be made that will have a structure similar to that shown in Fig. 3. On lighter plate the cast structure is unavoidable. Where your plate material is heavy enough, the work may be deposited in layers composed of strings of beads applied directly to the face of the scarf. When one layer of the weld metal is completely deposited, if it is peened with an air-hammer and roughing tool, the cooling strains may be removed by the metal being stretched. If a second layer of metal is now applied over the first, the heat of this second layer will have a tendency to anneal the first layer, giving us the structure that is shown in the accompanying photomicrograph. We can also obtain a uniform structure in our arc weld by furnace annealing. Fig. 4 shows the structure of the weld shown in Fig. 1 after it has been heated to approximately 780 deg. C. and then furnace cooled. It will be seen that the

coarse structure shown in Fig. 1 adjacent to the line of fusion has been entirely removed. So much for good welding.

You may ask why there has been so much adverse criticism of arc welding. The answer is that there has been considerable poor arc welding done, mainly because the operators were not thoroughly acquainted with their process. It is comparatively easy to hold an arc and melt a piece of welding wire, but to maintain the correct welding conditions is quite another thing. If your current is too low or you have your polarity reversed you also get a deposit of metal, but when subjected to a strain you will find that the weld metal has united with the plate about as much as molasses candy does with a marble slab, the lack of fusion

Fig. 10. Metal Shown in Fig. 9 Magnified Ten Times Greater

being due to insufficient heat. If too high a current is used the added metal and the adjacent plate metal will be burned. Much oxide will be introduced into the weld and a weak joint will result. Fig. 5 shows a section of a weld made using excessive current. You can see the large areas of oxide along the scarf line and the large black areas are voids formed by the entrapped CO_2 that was formed by the decarbonization of the plate metal along the scarf line.

Fig. 6 shows an oxide inclusion, a result of poor operation.

A great many arc welds are very hard and brittle. This is due in most cases to the presence of excessive nitrogen in the weld. If a piece of very soft iron be heated in an atmosphere of nitrogen at 760 deg. C. and cooled in it, the metal will become so brittle that a 5/32-in. wire so treated may be snapped like a piece of wood. Upon examination under the microscope, we find the structure as shown in Fig. 7. The short lines are iron nitride and may be found

in poor arc-weld metal. The greater the number of lines, the more brittle the weld.

The deposited metal obtained when using an excessive current is usually of a very poor structure. Fig. 8 shows the deposited metal obtained using too high a current. This metal was deposited from a 5/32-in. wire, using over 200 amperes, and it will be seen that there is considerable foreign material present. The grain boundaries are filled with oxide, and if a careful examination is made, the characteristic needle-like structure shown in the nitrogen-saturated metal can be seen. The metal is very brittle and in many cases will crack along the oxide-laden grain boundaries during cooling. Compare this metal with metal deposited at the proper current. Fig. 9 shows arc-deposited metal that is clean and free from impurities. This metal was deposited from a 5/32-in. wire, using 130 to 150 amperes. It will be noticed that the structure of this metal is more or less annealed, which makes it soft and capable of being chipped, drilled or machined. Fig. 10 shows a section of this same piece of metal magnified ten times greater. This shows what a clean deposit of metal may be obtained.

In spite of the ease with which a poor weld can be made, good electric-arc welds can be and are made where the operators have been properly trained and supervised, have good equipment and the proper welding materials.

Metallurgy of Welds*

By George A. Ellinger†

The art of welding has advanced far in the past few years. It is unnecessary for me to enumerate the points of advance, nor dwell long upon their importance, for this is fully known to you, as men of the welding profession.

While much has been done in the development of the art of welding in the past ten years, yet another ten years will show as complete an advance as that of the past. This art is coming to the front more every day, as an inexpensive and quick medium for the securing of results, a short time ago considered infeasible.

It has been but very recently that the metallurgy of welds has been religiously studied, and we may say that welding metallurgy is yet in its infancy with much to be learned by careful and wholehearted investigation upon the part of men skilled in the application of metallurgical principles.

Welding itself is entirely a metallurgical process. The molten steel in a weld has been said to be similar to the molten steel in our open-hearth or electric furnaces, and the weld itself has been compared to a casting.

These statements, while true in a sense should not be misleading

*Presented before Chicago Section A. W. S., Feb., 1926.

†Page Steel & Wire Co.

to the welder, for there is a vast difference between the molten steel in a weld, and the steel in the open-hearth. While possibly alike in character, the methods of treatment and handling are far different.

Steel in the molten state consists of one intimate chemical and mechanical mixture of iron, carbon, manganese, phosphorus, sulphur, silicon and various alloying elements.

In the steel which we shall consider tonight, that is under 0.90 carbon, the carbon is found entirely as a carbide of iron and of manganese. Possibly some small amount may be found as carbon dioxide, a gaseous substance, included in the steel itself. It is upon the carbon that the steel depends for hardening qualities.

Phosphorus is present as the phosphide iron, and is usually well scattered throughout the steel. Steels high in phosphorus have a characteristic brittleness well known to all steel men.

Sulphur in steel is usually found as the sulphide of manganese, which constituent of steel will cause little or no harm if present in small quantities and well scattered through the mass of steel.

These then are the most important elements found in steel and which are necessary in the discussion of the metallurgy of welds.

When steel cools from the molten state, it crystallizes somewhat similar to water when forming ice. These crystals are numerous, and they soon prevent each other from assuming any definite form. They form from a nucleus and grow, this growth continuing until retarded by another crystal. Because of the indefinite form of these crystals, they have been called "grains" by metallurgists, and as such we shall consider them this evening.

Steel consists of thousands of these grains, intimately locked together on all sides, by other similar grains.

This preliminary explanation is necessary, in order that all may have at least an idea of what a grain might be, for it is principally upon these grains that we wish to continue.

Steel to have its best properties must consist of a large number of very small grains, for it has been well proved that the smaller the grain, the more ductile and workable the steel. Large grains promote brittleness and have little ductility. In general a small grain may be effected by a quick cooling from a light temperature, and a large grain by a prolonged cooling.

The ideal structure for any metal, but for our particular problem, that of a weld, is a small grain, carrying with it a good tensile strength, a good ductility, elasticity and a strong bond between grains, for a weld may be said to be no stronger than its weakest grain bond, for it is there that fracture starts.

The general grain of a weld is not extremely large, although large grains have been found in certain welds. Thus there is one point of advantage to start.

In the making of a weld, the steel of the stock metal is somewhat heated, and assumes a larger grain structure than the weld usually does. At times the steel is badly overheated and even burned. The

grain of the weld proper may be smaller than that of the stock metal, and, as very often happens, the stock metal may break very close to the weld, while the weld yet remains in excellent condition. This is the reason why so many welders put forth their claim that the weld is always stronger than the stock.

In some cases the steel of the stock is burned, that is, oxidized by the action of the heat and the surrounding air. Burned steel consists essentially of a border of iron oxide extending around the grain boundaries, preventing a complete cohesion of the grains. Burned steel is always brittle because it takes but little strain to pull these grains apart. A somewhat similar brittleness is noted in red short steel, a steel of high sulphur content, wherein the sulphur unites with some of the iron forming iron sulphide. This when going to the boundaries of the grains creates a somewhat similar condition to that of burned steel in effect.

A good welder will not burn steel, nor will he excessively heat the surrounding stock metal, to such an extent that it becomes badly overheated. It is this overheating that causes more trouble with welds than any other. The ideal condition would be to preheat the stock metal to a temperature of approximately 850 deg. F., and then make the weld. This will give a gradually decreasing grain size, away from the weld rather than an abrupt change, very close to the weld.

A good welding job may always be made even better by a heat treatment. This, in effect refines the grain, making a more ductile weld. With low carbon rods and stock, the temperature of necessity is higher. In some welds which have been made, using a low carbon rod, where the stock metal was under 0.20 carbon, the best annealing temperature was approximately 1700-1750 deg. F., and held at that temperature for a few minutes followed by a fairly slow cooling. In some cases this refines the grain of the weld in excellent shape, but leaves the stock metal in a rather unrefined state. This may be corrected by giving it second annealing, at a somewhat lower temperature, approximately 1400-1500 deg. F. This gives a well refined grain in both weld and stock. The higher temperature is necessary in refining the weld grain, which you know, has solidified entirely from the molten state, with no heat treatment or work of any kind being performed upon it.

This, then covers the weld proper, and we will consider the most important constituent of the weld, the rod, the material with which the weld is made.

It has not been such a long time ago that it was considered proper to use any kind of wire for welding purpose. As long as the carbon was approximately right, the wire was considered as being suitable for welding. However, in recent years, the specially processed welding rod has been brought to the front, and today should be used by all welders and recommended by all welding men.

First of all the welding rod must, of necessity be made of good clean steel, for impurities in steel, such as dirt and other foreign

inclusions may cause no end of trouble. Dirty steel will cause the weld to boil and throw off sparks during the welding operation.

The steel should comply to the specifications as adopted by the American Welding Society. It must be made under chemical control and meet chemical requirements. Sulphur particularly must be kept low, for as was said before, high sulphur causes a brittle steel and that is one thing which welders wish to avoid.

A welding rod, not only must meet chemical requirements, but each rod must be specially processed to secure a good grain structure, and this processing is different from that of other grades of wire on the market. The wire is preferably cold drawn, as this will eliminate any inclusions of iron oxide, and scale, which might possibly have been picked up, had the rod been hot drawn, or rolled. We have already seen what iron oxide will do, if included in the weld.

Manufacturing companies today realize the value of a processed rod, and are endeavoring, by research, to find the best rod, that may be found for any certain purpose. Quality of steel, wire drawing methods and the heat treatment of steel are all under study and observance. All this is attended by close chemical and physical control during the entire process, so that each welding rod may have exactly the same properties and act the same in welding, as does its neighbor. This is all to aid the practical welding man in the securing of good permanent welds, and to aid the art of welding to advance to the place in metallurgical fields where it rightfully belongs. Welding is a great aid to mankind, without it we would be at loss to replace broken parts or to rebuild and renew the worn ones. As men who are interested in the advancement of welding, I wish to congratulate you in your successes of the past, and wish you success in the development of that great and necessary profession—welding.

Reclaiming Locomotive Main Rods

By JOSEPH MURPHY†

A steel back end main rod strap is difficult to hold securely, owing to the heavy stresses set up in the reciprocating parts of a locomotive. In time, owing to repeated reaming at each shopping, the holes become so large that both the rod and strap are weakened to such an extent that they cannot be continued in service. About three years ago we conceived the idea of filling these holes with thermit steel and reclaiming the rod by a process which has proved satisfactory and profitable.

Preparing the Rod

The stub end of the rod is thoroughly cleaned and three wooden plugs are driven into the holes at the small end of the taper. The plugs are waxed, as shown in one of the illustrations. The rod

†General foreman, Boston & Albany Railroad, West Springfield, Mass.

is then placed so that the plugs are on the bottom. A sheet steel box 14 in. long, 10 in. wide and 14 in. deep, constructed of 3/16-in.

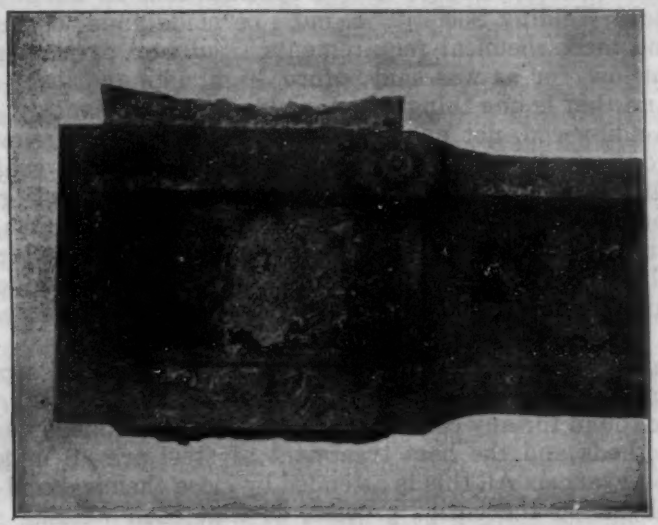

Fig. 1. The appearance of the weld before machining

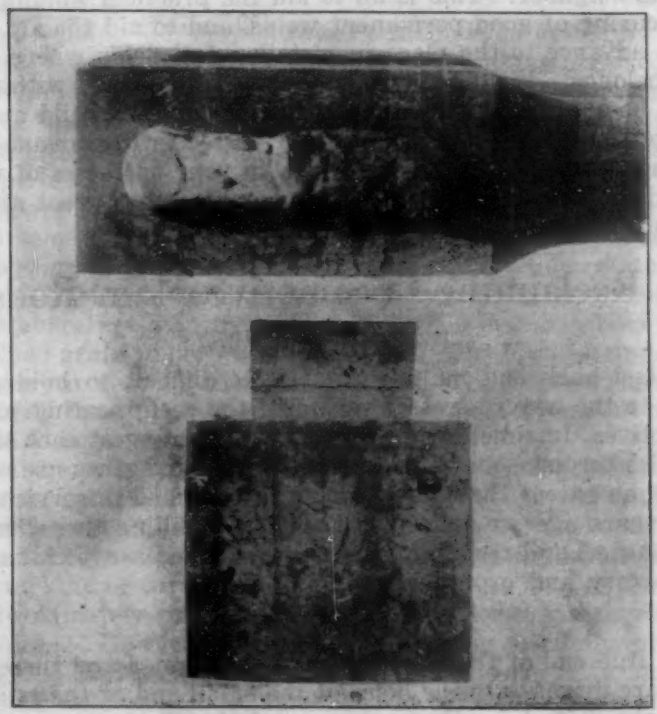

Fig. 2. The top view shows the wax mold in place while the lower view shows the mold box and the position of the wooden riser plug

steel is set on the end of the stub so that there is a clearance of about 2 in. between the rod and the bottom of the box to allow for the ramming of the sand under the rod. This box serves to hold the mold which is built around the rod. The sand is rammed at the bottom and sides to the top of the rod. A wooden block is then placed over the holes, the base of this plug being sufficiently wide to project about ¼ in. beyond each side of the holes. The sand is then rammed around this block, and the edge of the mold dented to prevent the metal and slag from flowing over the box. The plug is then removed, thus forming a riser for the metal. The end of the rod with the box and mold is then inserted into an oil furnace and allowed to heat for about two hours to bring the temperature to about 1550 deg. F.

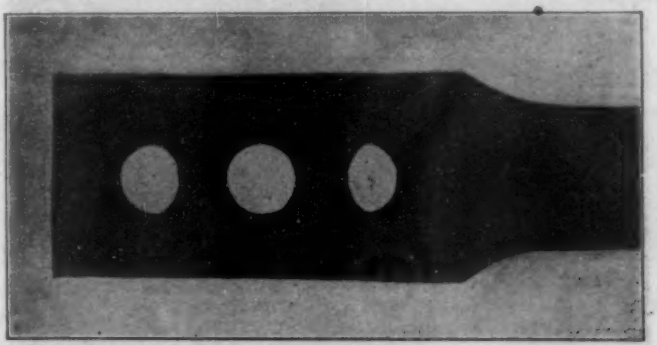

Fig. 3. The stub end of the rod thoroughly cleaned preparatory to the Thermit weld

While the rod is heating the welder prepares his crucible. About 40 lb. of railroad thermit is charged into the crucible, the ignition powder placed on top and the cover applied, after which the crucible is suspended from a jib crane to allow for adjustments. The rod is then removed from the furnace, levelled and all particles of sand and scale blown out of the holes. The crucible is then adjusted so that the tap is directly over the riser and high enough so that it can be swung over, if necessary after tapping the mold. The reaction is started and 25 to 30 seconds later the crucible is tapped. The plugs which have been burned during the preheating rise to the top, allowing the thermit metal to fill the impression made by them at the bottom of the mold. The weld is then allowed to cool for about 14 hr. after which it is stripped as shown in one of the illustrations. The rod is then machined in the usual manner.

The total cost of the operation, including labor, cost of material and subsequent machining, is $24.50 a rod. The cost of a new rod is approximately $136, showing a saving of about $111.50 a rod.

The Effect of the High Temperatures on the Original Steel

When we first started to use this process it was suggested that the high temperature of the thermit steel might have a deteriorating effect on the structure of the original steel with the possible

result of a rod failure on the road. As a result of the suggestion we made a test which proved to our satisfaction that such a condition did not occur.

A rod was prepared in the ordinary way; that is, the mold was built around the butt end and this portion of the rod, together with the mold, was preheated in the furnace to about 1500 deg. F. The thermit was then poured and the mold allowed to cool for 14 hours before stripping. This permitted the welded end to cool slowly and refine the grain.

After stripping the mold, the entire rod was annealed after which 1-in. holes were drilled through the poured thermit. The butt end was then cut in two, splitting it longitudinally. The piece

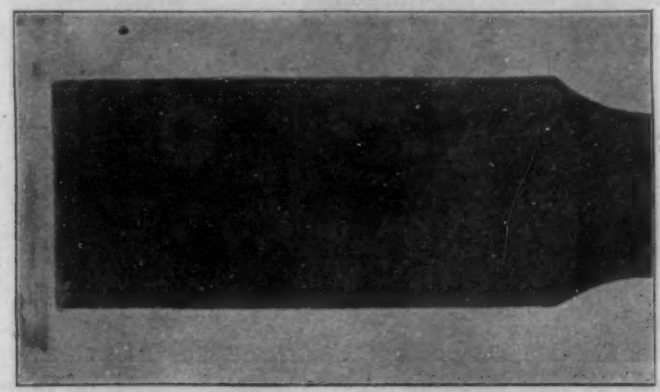

Fig. 4. The rod looks like a new one after machining

was also fractured at the point where the weld was made. It was found that the weld was perfect and homogeneous. A specimen as cut off the portion of the rod containing the original steel, fractured, and the grain at the fracture compared with the fracture across the weld. It was found that the grain had not become coarser on account of the extereme thermit heat and was practically like the original stock. Several scleroscope hardness tests were made. The welded specimen tested 29 hard while the original stock tested 31 hard.

Providing that the mold after pouring is allowed to cool slowly before stripping, the steel has a tendency to refine its grain and will have practically the same structure as the original stock of the rod. The lower scleroscope reading on the welded metal is undoubtedly due to the fact that the material in this section of the rod had been annealed twice and was a trifle softer.

Oxy-Acetylene Welding of Copper*

By S. W. Miller†

Next to iron, copper is the most important industrial metal, and its use, both in the pure state and in such alloys as brass and bronze, is very great.

The process of refining copper during its manufacture is of interest as explaining the difficulties in welding it, which have been referred to in welding literature since the early days of the process.

Fig. 1. Average view of the distribution of copper oxide in commercial copper plate. These inclusions are gray blue in color. Unetched. 100X.

After the preliminary processes that remove the gold, silver and other valuable elements, as well as the undesirable ones, the copper is further prepared for casting into pigs. As it has a strong affinity for oxygen when molten, it becomes saturated with it during the melting, and if cast in this saturated condition, the pigs will be brittle, the center of their top faces will be lower than their edges, and the pigs will have a bad appearance.

This is overcome by stirring the melted bath with poles made of green wood, the process being called poling. If poled too long, the pigs will rise in the center, and will be porous. When the poling is carried to just the right point, the pigs will have a flat surface and will still be free from porosity. Such copper is called "tough pitch."

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*Presented at Pittsburgh Section, February, 1926, and New York Section, A. W. S., March, 1926.

†Consulting engineer, Union Carbide and Carbon Research Laboratories.

This material, the usual commercial product, still contains a considerable amount of cuprous oxide, Cu_2O, and due to its presence, has a peculiar property when hot, in that for some distance below its melting point it is brittle and cannot be hammered or rolled, the maximum working temperature being a dull red. This brittleness

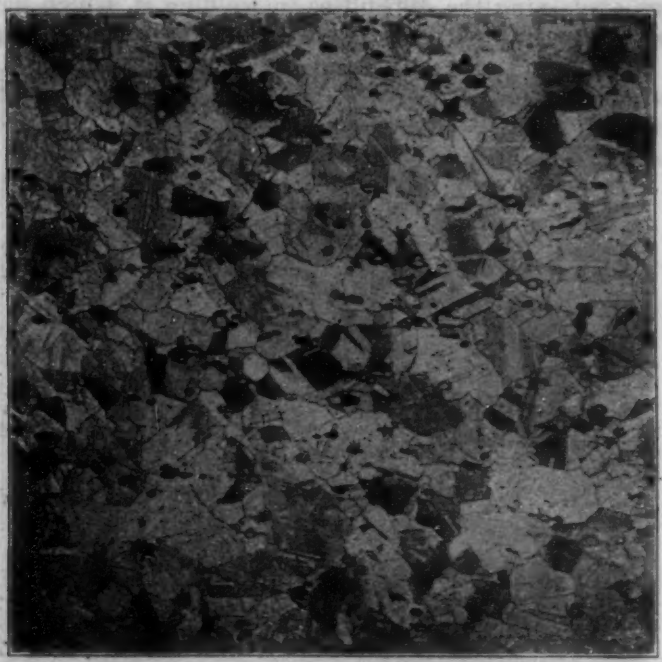

Fig. 2. Average view of the structure of commercial copper plate showing the distribution of the copper oxide. 100X.

is a maximum just below its melting point, at which temperature it has practically no strength, so that just after the welding operation is completed, if there is any stress at all in or near the weld, cracks appear in either the weld or base metal, and as they cannot be welded, the operation is a failure.

The same general statements are true when either ordinary brazing or bronze welding of copper is resorted to, though the damage is not so great in these cases. It is very easy to overheat copper in either way, and reduce the resistance of the joint to a point that is dangerous where high strength is needed.

Much effort has been wasted in trying to correct this trouble by the use of special welding rods containing various deoxidizers. But it has very seldom been recognized that even if the weld metal is clean and strong, the damage is still present just next to the weld in the base metal.

About four years ago the author made a series of tests of copper welding rods containing such deoxidizers as silicon, manganese, aluminum, phosphorus, and various combinations of them. Some

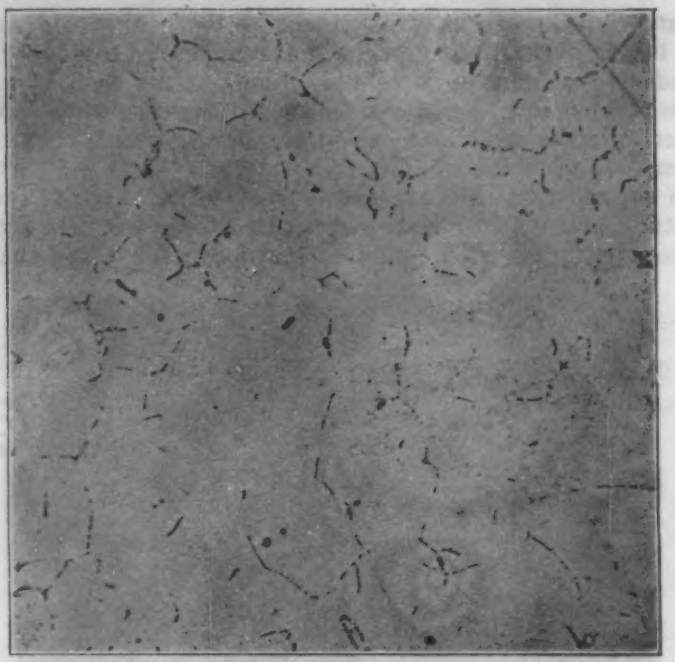

Fig. 3. A general view of the distribution of the copper oxide in the base metal just below the weld metal. It has assumed the apparent outline of the grains. Unetched. 100X.

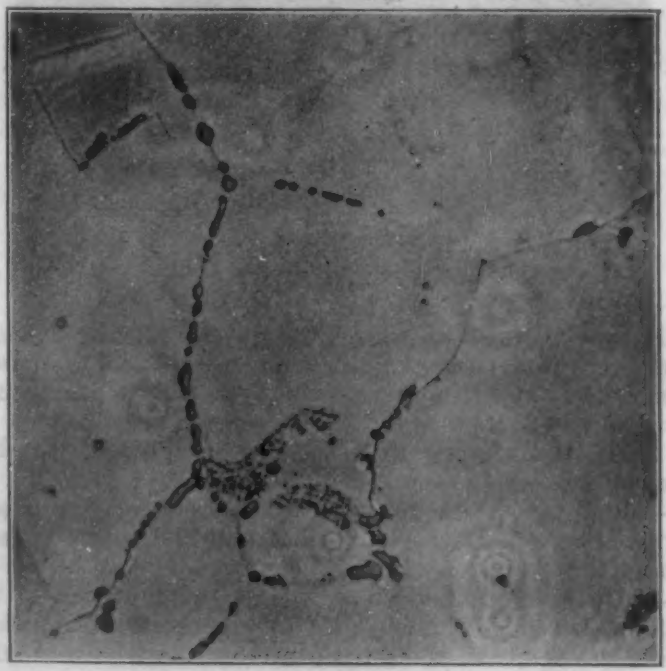

Fig. 4. View within the area in Fig. 3 at higher magnification showing that the oxide has formed around the grain boundaries of the copper and, on the right side, has joined with the copper to form an eutectic. Etched. 430X.

of them seemed to work well under the torch and to give sound welds, but rather strangely, when the rupture of a test piece, either by bending or in tension, occurred outside of the weld, it was just next to the V, parallel to its side, and in the case of tensile tests, at practically the same load per sq. in. of base metal, regardless of the composition of the welding rod.

This showed that the base metal must be defective at the point of rupture, and that the rods had nothing to do with the difficulty.

Of course, it has been common knowledge for years that com-

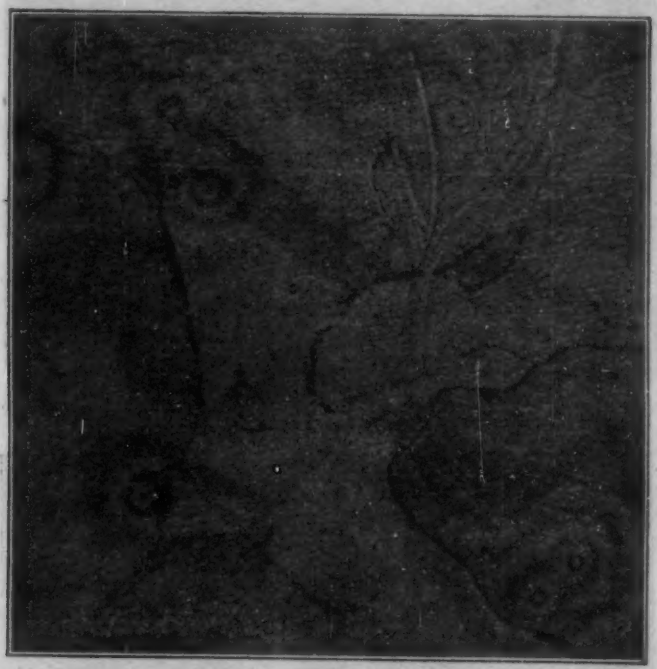

Fig. 5. Another view of the oxide at the grain boundaries just beneath the weld. It will be noted that the grain in the southeast corner appears to be outlined completely by this oxide. 430X.

mercial copper is injured when heated by a reducing flame, but it does not seem to have been realized up to the time of these tests, that the trouble with copper welding was due to this cause, the reducing flame of the welding blowpipe being responsible.

The action is really two-fold, as was brought out clearly by a microscopic examination.

1st—The thin melted zone just next to the V recrystallizes when cooling, and any oxide present collects at the grain boundaries, weakening them and therefore the metal.

2nd—Such of this oxide as is exposed to the action of the envelope flame is reduced to copper, which, occupying less space than the oxide, leaves spaces along the grain boundaries, weakening the metal still more.

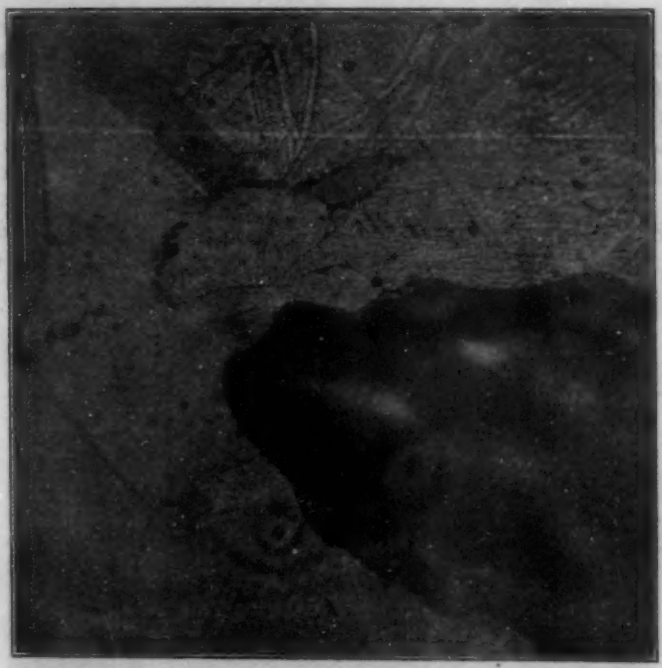

Fig. 6. The specimen from which Fig. 5 was obtained was bent slightly. The result was that the grain outlined by the oxide dropped out. This is definite evidence of the lack of strength of the oxide films in the copper.

Fig. 7. Commercial copper welded with a bronze welding rod. This specimen was bent while under the microscope. The first ruptures are at the grain boundaries of the copper just under the weld. 430X.

This reducing action is very rapid, as can be seen by playing the envelope flame across a surface of scaled copper. As soon as the scale has become red hot the surface becomes of the usual copper red color, only a few seconds being needed for the change to occur.

Sections of welds bent slightly and examined under the microscope showed that the path of rupture always followed the visible defects at the grain boundaries.

As the primary cause of the trouble was evidently the cuprous oxide in the metal, some deoxidized copper was made by casting

Fig. 8. Commercial copper bronze welded. This shows that in bronze welding, the temperature at the surface of the copper is sufficient to cause the copper oxide to be rejected to the grain boundaries as in welded copper. 430X.

ingots 2 in. square and forging them to the desired size.

Silicon was found to be by far the best deoxidizer, and only a small residual amount of it was found necessary, say from 0.05 per cent to 0.10 per cent. There was no difficulty at all in forging it at a sweating heat, that is when it was almost melted, and at no temperature below this was there any cracking.

Welds were made in this material with the different rods, and much improvement was found. But the best results were not obtained till a welding rod of a composition similar to the base metal was used. Table I shows some of the results obtained under tensile test, and makes clear the superiority of the combination.

As properly deoxidized copper can be forged easily at any temperature, there can be no danger of welding strains cracking it,

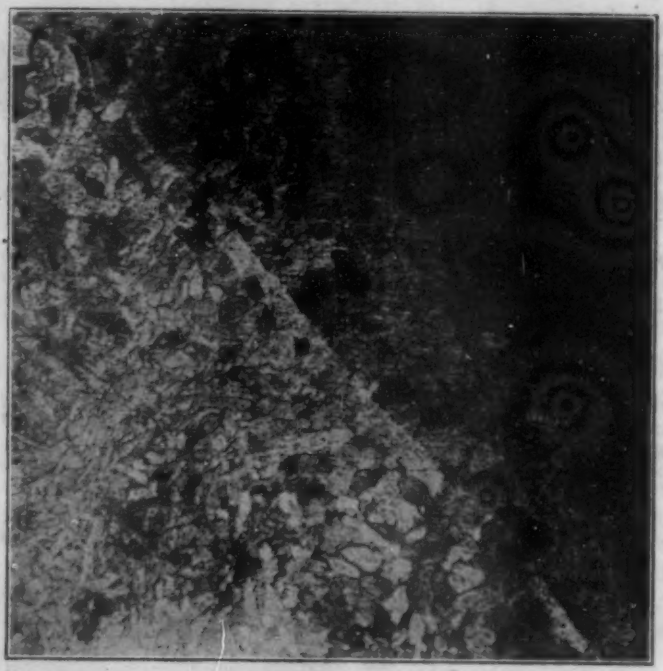

Fig. 9. This shows the location of the final fracture in welded commercial copper tested in tension. The failure was within 1/100 inch of the weld line. 100X.

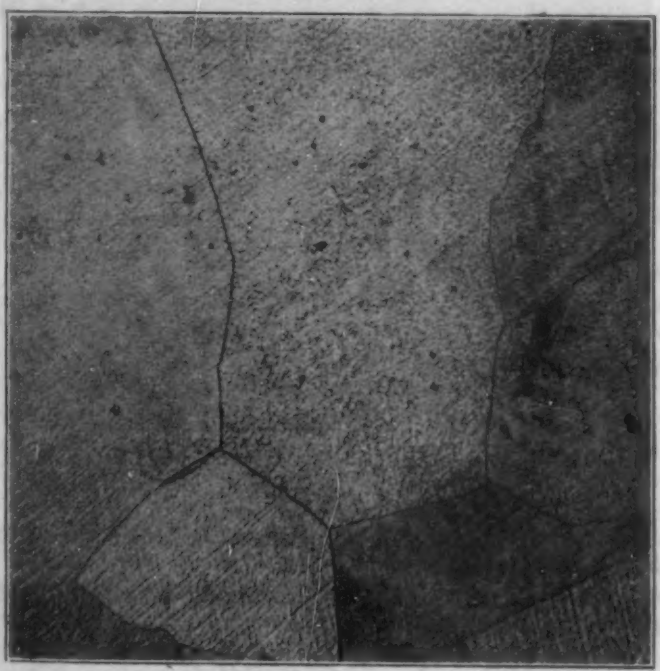

Fig. 10. A general view of copper weld metal made with a welding rod containing about 1.0 per cent silicon. The metal is clean and sound. 100X.

Welds in Commercial Copper

Welding Rod Symbol	Deoxidizer	Tensile Strength, Lb. per Sq. In.	Elongation in 2 In., Per Cent
CS0	Silicon	14,800	6.25
CS1	Silicon	16,450	8.7
MS1	Manganese Silicon	15,100	7.0
CP1	Phosphorus	14,150	8.7
	Welds in Deoxidized Copper		
CS0		29,450	30.0
CS1		28,800	32.5
MS1		28,650	27.5
CP1		19,600	13.7
	Average of a Number of Welds in Each Type of Plate		
		Ultimate Strength	
Commercial plate		15,520	8.1
Deoxidized plate		26,280	23.0
Original plate		32,000	...

None of the welds was hammered or heat treated. Such treatments would improve the physical properties.

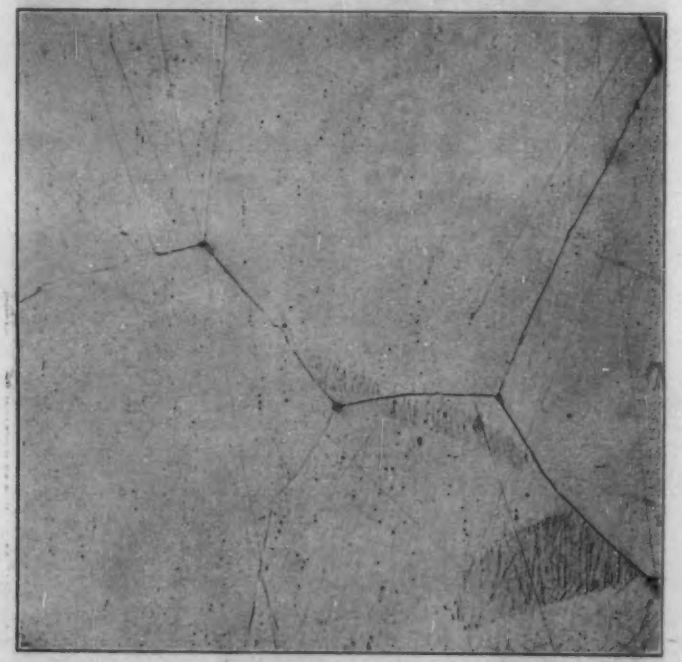

Fig. 11. An average view of copper plate deoxidized with silicon. There are no copper oxide inclusions. Due to the cleaner metal the grains are larger than in the commercial plate. 100X.

and as it is just as malleable as commercial material, there is no trouble in cold working it.

There is also no difficulty in obtaining it, as any manufacturer will make it if asked to do so.

It is probably true that the complete realization of the possibilities of copper welding will cause an increased demand for welded

copper products, which will be of great advantage to industry in many lines.

It should be understood that the presence of oxide can be positively determined by the microscope, or practically by heating a piece of the metal to a bright red and bending or forging it. If it cracks, oxide is indicated, and even if by chance something else causes the cracking, it is not fit for welding and should not be used.

The photomicrographs show the structures referred to.

Welding and Cutting Die Parts

By J. W. Meadowcroft*

In a die department, the method of cutting strippers by oxy-acetylene is used extensively and as each stripper is somewhat different in design you can fully realize how expensive this operation would be if we were to cut same with a hack-saw or cold-saw as was done in the past. Seeing the oxy-acetylene operator cut this material reminds one of a tailor cutting cloth. The stripper material need only be marked with chalk from a paper template and any size or shape stripper can be cut accurately and economically with a cutting torch. No machine or die shop could successfully compete today without the use of this invaluable tool. Many pieces could not have been cut out by hand or machine in past years, as they are today. It was then necessary to have the pieces so designed and constructed that they could be pieced together. These strippers probably answered the same purposes as those made under more modern methods, but the cost was many times greater.

This procedure is also used for cutting die parts on some classes of dies where it is not necessary to use a high carbon steel, but the oxy-acetylene welding of dies and die parts is used very successfully regardless of size or weights. In the future, many dies and large parts of machinery which are broken will be repaired without removing same from their location. This will represent a large saving, as it is often necessary to have several men spend two or three days removing parts of large machines to procure the part which is broken and then consume the same amount of time in reassembling the parts of machine after the broken part has been repaired. It also means that the production of materials from the machinery will increase many times through the use of this method. It will enable a reduction in the force of maintenance men, thus reducing the overhead. Another important item to which this method will be applied is the building up of parts which have worn away from continuous use and the repairs of dies, jigs, and fixtures.

To handle this work the arc welding method will be employed and, although today it is being used to a small extent along these lines, it will be developed continually by the users of welding equipment and applied in accordance with these conditions. Like any other art, it takes a certain amount of development work, and we are now going through this development period.

*Superintendent, E. G. Budd Mfg. Co.

Atomic Hydrogen Arc Welding

By R. A. WEINMAN† and IRVING LANGMUIR†

It has been shown that a stream of hydrogen directed into an arc between tungsten electrodes can be made to produce a flame of atomic hydrogen which is of even higher temperature than the oxy-acetylene flame. To utilize this flame for the welding of metals it becomes important to have easy and complete control of the flame. The welding torches and auxiliary apparatus that have been developed for this purpose will be described in the following pages.

The Welding Torch

Many different forms of welding torches have been constructed and tested. The electrodes between which the arc passes are mounted at a convenient angle to one another and are adjustable so that they can be brought into contact at a point which is exposed to a blast of hydrogen from one or more orifices. Thus the atomic hydrogen is blown out of the arc in a definite direction and forms a flame which can be brought into contact with the metal to be welded. The jet of hydrogen also serves to bathe all the heated parts of the electrodes and the work, thus preventing oxidation and the introduction of impurities such as nitrogen into the weld.

Fig. 1 illustrates two of the torches which have been extensively used. The electrodes, consisting of tungsten rods $\frac{1}{8}$ in. in diameter, are held in position at an acute angle with each other by lava insulators.

In the torch shown at the right in Fig. 1 the electrodes are kept in contact by the spring when not in use but may be separated as much as about $\frac{3}{8}$ in. by applying pressure to the lever which is mounted on the handle. Slow adjustments of the electrodes are made by the set-screw attached to the lever.

The hydrogen is supplied by a tube which passes through the handle and then by flexible tubes is delivered to each of the electrode holders and escapes through the annular spaces between the electrodes and the lava insulators. Sufficient hydrogen is used not only to surround each of the electrodes to their tips but to form a blast which blows the atomic hydrogen against the work and bathes it in hydrogen.

In the torch shown at the left in Fig. 1 a jet of hydrogen is directed into the arc from the end of the tube which projects from the hemisphere while a stream of lower velocity hydrogen escapes from the small openings in the hemisphere and thus surrounds the electrodes and the work with a bathing gas.

Some torches, for use with 3-phase currents, have had three

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†Research Laboratory, General Electric Company.

movable electrodes arranged symmetrically like the three edges of a triangular pyramid. Although the 3-phase arc is found to possess certain advantages, particularly in regard to stability, the added complication of the third electrode usually more than offsets these advantages.

Electrical Apparatus

Both the striking voltage and the arc voltage are higher for an arc in hydrogen than for the ordinary welding arc since there is no appreciable amount of metallic vapor generated in the arc. The

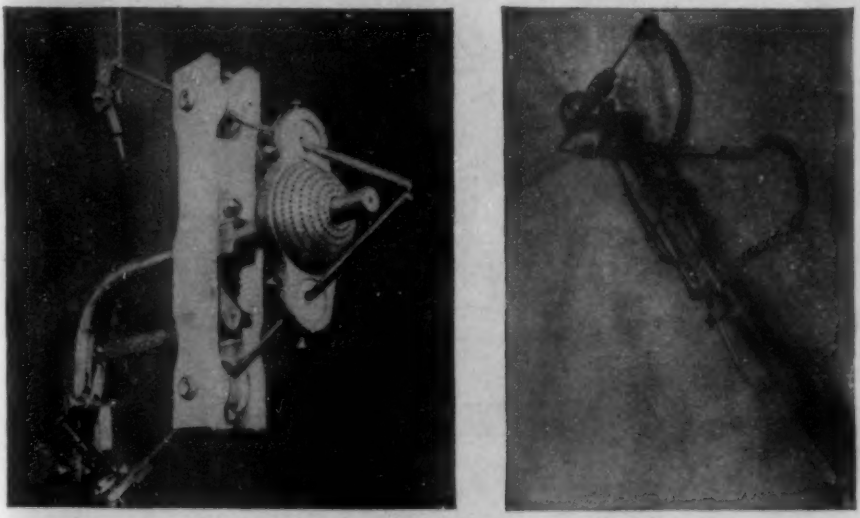


Fig. 1. Two Types of Atomic Hydrogen Arc Welding Torch

present day standard arc welding equipment is therefore not suitable as a power source for operating the atomic hydrogen torch.

If direct current is used the arc may be stabilized by a series resistance, or a specially designed generator of the constant-current type may be used. With series resistance a line voltage of 250 has been found to give good results.

Alternating current is more convenient and, since the arc can then be stabilized by reactance instead of resistance, greater efficiency is usually obtained. A line voltage of 350 to 400 gives satisfactory operation. Voltages as high as this are needed solely to give stability and to enable the arc to be started at any time by separating the electrodes even when these are cold.

A number of tests have been made to determine the voltages required to strike an arc by means of the lever mechanism of the torch. With cold electrodes an open circuit a-c. voltage of 320 was needed for striking the arc. After the arc had been started and the electrode tips had reached the operating temperature a line voltage of only 150 was sufficient to restart the arc as

long as the electrodes remained nearly at the operating temperature. These lower line voltages may also be employed to start and maintain the arc if the electrodes are first raised to high temperature by a high current while separating them very slightly so as to have a high contact resistance or by bringing a thin tungsten rod between the separated tips of the electrodes.

It is more convenient, however, to use open circuit voltages of approximately 400 rather than to employ these special means of starting the arcs. In normal operation the drop across the arc

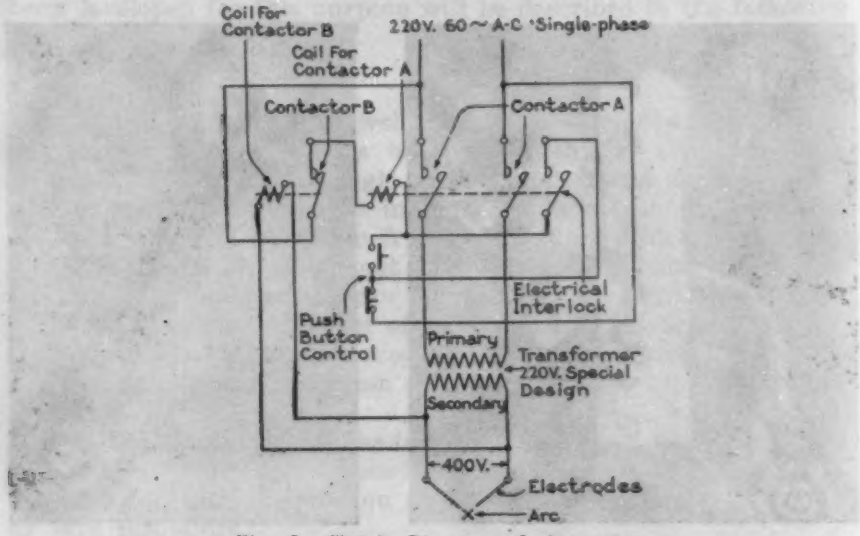


Fig. 2. Circuit Diagram of Apparatus Used with Atomic Hydrogen Welding Torch

is in the neighborhood of 80 volts. To avoid danger to the operator the entire arc circuit is preferably insulated from ground. A motor-generator may be used to give either direct or alternating current for the arc, but it is usually more satisfactory to use a specially designed transformer.

The connections that have been used in most of the work to be described are shown in Fig. 2 and will be readily understood. When the arc is not operating the electrodes are in contact by the action of the spring attached to the control lever, so that there are no voltages on the electrodes and the torch can be laid down on any material without danger of flashing the operator's eyes. To strike the arc the electrodes are merely separated by pressing the lever.

Should the open-circuit voltage at any time be impressed across the electrodes when separated, or the operator break the arc by spreading the electrodes too far apart a relay in the arc circuit (contactor B as shown in Fig. 2) will trip the feeder circuit, in which case it is necessary for the electrodes to be brought in contact again before the main feeder circuit can be restored.

The Welding Arc

The torches illustrated in Fig. 1 are operated ordinarily with currents ranging from 20 to 70 amperes, depending mainly on the thickness of the material being welded. Where greater currents than this are required ¼-in, and ½-in. electrodes are used, special supports being necessary for them.

In the few recent experiments, illustrations of which will be shown later, low carbon steel samples, containing 0.20 C, in sheet form of different thicknesses, were welded with the currents shown in the following tabulation:

Thickness in inches.....	⅛	3/16	¼	⅜	½
Amp 30	40	50	60	70	

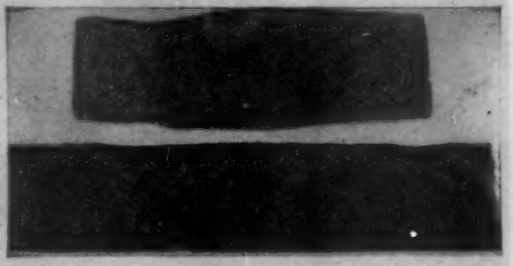


Fig. 3. Soft Steel Weld—Hydrogen Gas Used Alone

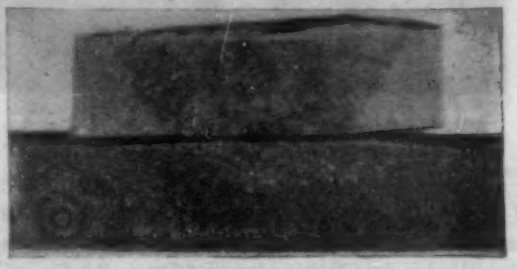


Fig. 4. Soft Steel Weld—Hydrogen and Nitrogen Used in Equal Proportions

Thorough penetration was obtained for each reading taken, the rate of welding on 4-in. lengths being from 15 to 20 ft. per hour. Alternating current was used in practically all work.

The voltage drop across the arc while in operation varies from 60 to 100 volts, depending on the amount of opening between the electrode tips. This voltage is nearly independent of the current, between the limits of 20 and 70 amp., although a slight decrease in voltage is usually noted when the current is increased. Repeated experiments have shown that the lower voltage arc (60 to 80 volts) obtained by separating the electrodes only 1/16 or ⅛ in. has a more concentrated working zone and is the most efficient arc for most kinds of welding.

The rate of consumption of gas used per torch for ordinary welding varies between 20 and 30 cu. ft. per hour, depending to some extent on the amount of surface of the work to be covered. For outside work, however, especially in windy places, these amounts may be increased. The gas pressure required to operate the torch is very small; in the laboratory where short lengths of hose were used, a pressure of less than one pound per square inch was sufficient to weld metals 3/8 to 1/2 in. thick.

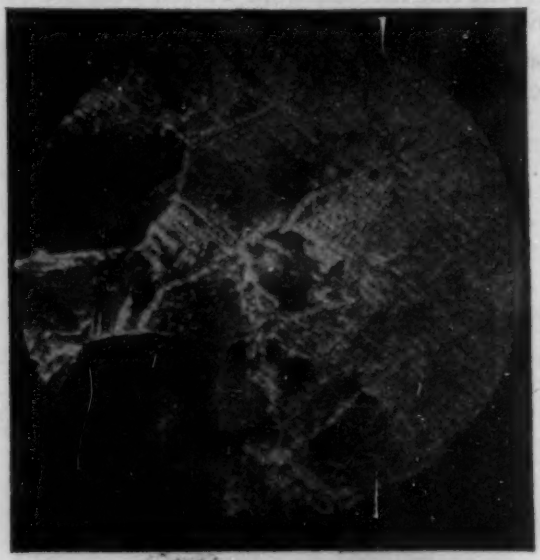


Fig. 5. Photomicrograph of the Weld in Fig. 4

A test for consumption of electrodes was made with alternating current and was found to vary greatly with the depth of penetration of the weld. On all metals up to 1/8 in. thickness, less than 1/64 in. of the electrodes was consumed per 24 in. of joint welded, while with thicknesses of 3/8 and 1/2 in., 1/64 in. to 1/32 in. of electrode was consumed per inch of joint welded.

With direct current one electrode becomes much hotter than the other and this increases the consumption of electrodes and may necessitate electrodes of larger diameter.

With two electrodes, the number commonly used, a fan-shaped arc is obtained which has a very narrow cross-section and a spread of 3/8 in. to 1/2 in. This arc, when the current is 20 amp. or more, will melt an iron rod 1/4 in. in diameter when placed 2 in. from it.

By bringing the arc closer to the surface of a larger mass of metal it is found that the metal melts very rapidly. For welding, the maximum rate of heating is desired and this is obtained by bringing the torch so close to the metal that the lower portion of the fan-shaped arc is just about in contact with the metal and this

causes the arc to change its shape somewhat. The tip of the electrodes are then usually about ⅜ to ½ in. from the metal. Portions of the arc may at times become short-circuited by the metal so that the tracks of cathode spots on the metal may be seen, but this seems to play no important part in the welding process.

For good welding it is important to hold the torch inclined at about 45 deg. to the plane of the metal surface which is being welded so that the blast of hydrogen from the torch passes over the pool of molten metal in a direction opposite to that in which the torch is moved along the line of the weld. In this way the metal at every point becomes heated and melts very rapidly but

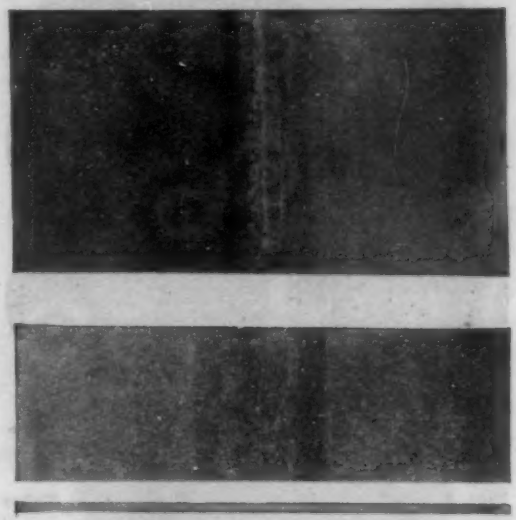


Fig. 6. Various Views of a Weld Made on Sheet Metal by a Full-automatic Welding Machine

cools comparatively slowly so that the dissolved gases have time to escape before the metal freezes. This solidification of metal at the fringe of the gas flame is responsible for the elimination of what are called gas pockets and inclusions and is one of the most important phases of the process. A welder with some experience in either electric or gas welding will observe this before many welds are made.

When the torch is inclined in the proper way to the plane of the work and is moved steadily along the line of weld, the molten pool is elliptical in shape, being usually about twice as long (or more) in the direction of weld as across it.

By inclining the torch in the manner described, the gases which escape from the pool usually in the form of bubbles, are blown away by the blast of hydrogen so that they do not disturb the arc. In this way the flame of atomic hydrogen preserves a constant shape so that a very uniform weld can be obtained.

Another advantage of inclining the torch is that the heat from the arc and the burning gases is prevented from unduly heating the torch and this tends greatly to reduce the consumption of the electrodes.

The Use of Gas Mixtures and Various Electrode Materials

Hydrogen when used alone in this process was found to possess many characteristics which mixtures of hydrogen with other gases did not have. One of the most important of these is that the arc itself is more steady and does not spread over as much area, the advantage of this being a narrower weld with greater penetration when using the same currents. Mixtures of hydrogen and nitro-

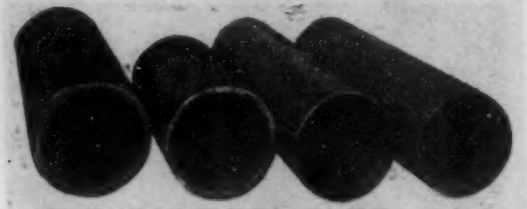
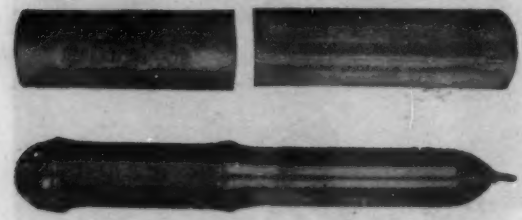


Fig. 7. Tubes Welded by the Hydrogen Arc



Figs. 8 and 9. High-chromium Welded Steel Tubes

gen, half and half, required an increase of arc voltage of 10 to 20 per cent over that for hydrogen alone, using the same currents in both cases. With this mixture of hydrogen and nitrogen the welds were ductile and solid.

Illuminating gas with graphite electrodes gave ductile welds on copper, and some of the non-ferrous metals, but gave very porous welds on steel. Where hydrogen is added to illuminating gas, up to 75 per cent hydrogen content, ductile welds were obtained on iron and its alloys. Graphite electrodes with hydrogen alone gave ductile non-porous welds on iron. However, the graphite electrodes, which were $\frac{1}{8}$ in. in diameter, required continual adjustment in all of these tests, due to the excessive rate of consumption. Approximately $\frac{1}{4}$ in. of the electrodes was consumed per inch of weld on $\frac{1}{8}$-in. copper.

Illuminating gas with tungsten electrodes gives approximately the same results as were obtained with the graphite electrodes. Using this gas and mixtures of hydrogen or air, tungsten carbide is formed which melts at a lower temperature causing globules of

this compound to form at the contact ends of the electrodes. The arc voltage is approximately double that of the hydrogen arc when illuminating gas alone is used as the medium.

Ammonia gas decomposed by passing through a coil of iron pipe heated to 650 deg. C., giving three parts hydrogen to one part nitrogen, can be used when hydrogen alone is not available. The

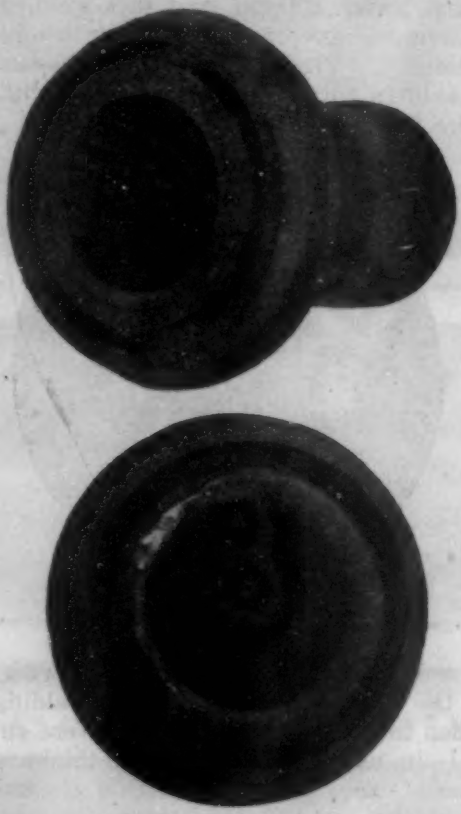


Fig. 10. Weld of Rectifier Seal, Joining Chromium and Low Carbon Steels

results obtained with this mixture were similar to those where mixtures of half and half hydrogen and nitrogen were used, requiring a slightly higher arc voltage compared to hydrogen alone.

When methanol decomposed by means of catalytic action into hydrogen and carbon monoxide gases, was used in the process, the attack on tungsten electrodes was similar to that with mixtures of illuminating gas with hydrogen. Tungsten carbide formed at the contact ends of the electrodes and an increase of approximately 50 per cent in arc voltage over that with hydrogen alone was required.

In the welding carried on in the laboratory the greater part has been done with hydrogen alone, other gases being used for com-

parative tests only. A great amount of work has been done on the various metals and their alloys in different forms of welding with hydrogen.

Materials Welded

Low carbon steels up to ½-in. thickness have been welded without additional metal by butting the ends together tightly so that no space remains between them, and tack-welding on both ends or in as many places as found necessary where they are not mechanically fastened. This sort of welding has also been applied to tubes when held in forms having a copper chilling bar immediately under the joint.

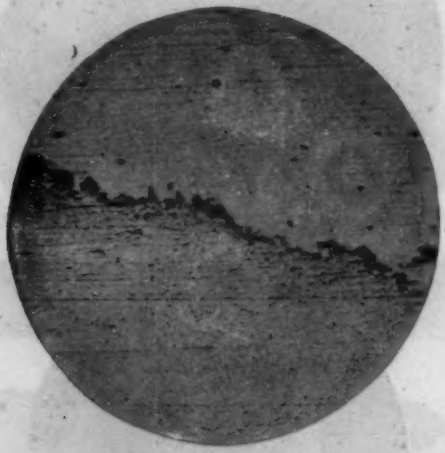


Fig. 11.. Silicon Copper and Soft Steel Weld (100 Diameters)

Considerable work was done in connection with full automatic welding where the same procedure as butt welding was used, no metal being added to the seam. The edges were cut by a shear in thickness up to ⅛ in. which is the maximum thickness used on automatic experimental work so far. In this work the metal was clamped on a chilling bar by air pressure or mechanical means. The arc mechanism was mounted on a movable carriage capable of speeds from 15 in. to 56 in. per minute. Here other gases were tried alone and in combination with each other, the hydrogen gas giving best results.

On welds with thicknesses greater than ½ in. where hand torches are to be used with currents not exceeding 70 amp., a small amount of space is left between the pieces to be welded, which enables the arc to penetrate to the full depth of the work, the remaining space being filled with added metal.

In some cases where pieces 1 in. thick were welded from one side only, V-shaped slots were cut along the seams to within ¼ in. from the bottom of the piece. Filler metal may be added if necessary to any thickness of weld. This metal may have the same

constituents as the parent metal or it may be lower or higher in carbon content. It may contain Mg, Cr, Mo, Al, W, Si, or impurities of S, P, etc.

Aluminum alone and in combination with iron (15 per cent Al-Fe

Fig. 12. Silicon Copper to Invar Weld—Enlarged

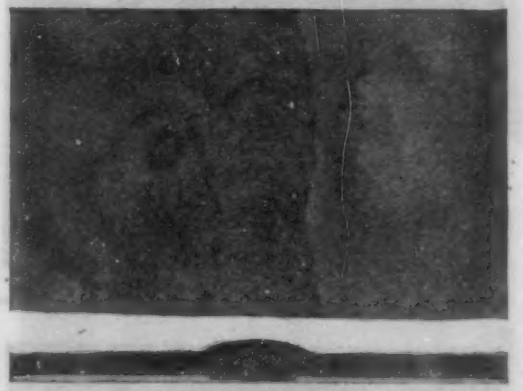


Fig. 13. Steel Weld Using Alloy Filler Rod

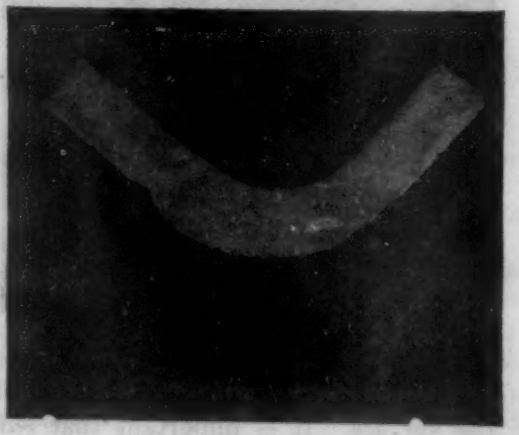


Fig. 14. Welded Joint Subjected to 90-deg. Bend

alloy) has been used for a final layer, covering welds made with low carbon steel. A number of different alloys of Al, Ni and Cr have also been used for filler rod.

Al and Ni alone or together may be welded by this process. They possess, however a tough oxide skin when in the molten state which

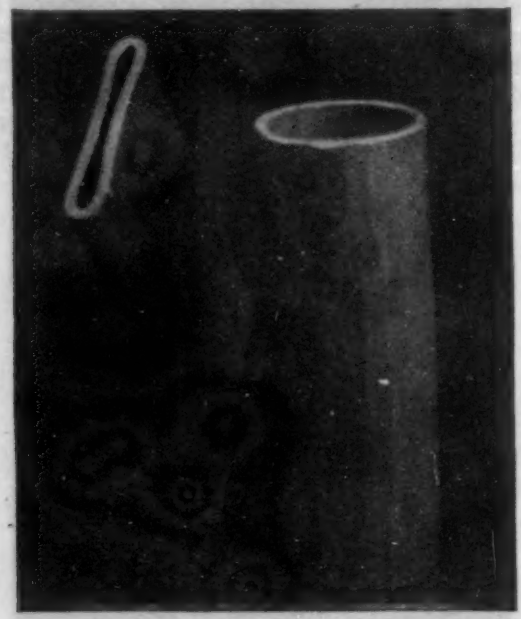


Fig. 15. Welded Tube Crushed at the Joint Without Damage

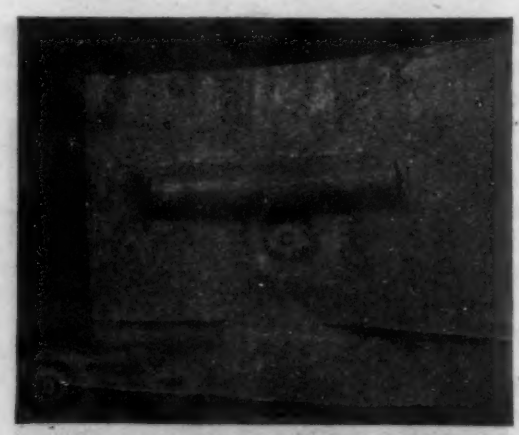


Fig. 16. Welded Material Subjected to Expansion

the atomic hydrogen flame breaks through when it is brought in contact with the surface. It is important that suitable chilling facilities be used in these cases, especially under the weld, due to

the intense heat of the arc. This chilling will prevent the metal from flowing away underneath. Many of the chrome-nickel alloys are similar to Al and Ni in this characteristic and also require chilling facilities immediately under the weld.

Test Data

Figs, 3 and 4 show a longitudinal and transverse cut through a low carbon steel weld (0.20 C) in which no additional metal has been added to the weld. Hydrogen alone was used in Fig. 3 while equal quantities of nitrogen and hydrogen were used in Fig. 4. The thickness of metal is 3/16 in.; the specimens were 4 in. long.

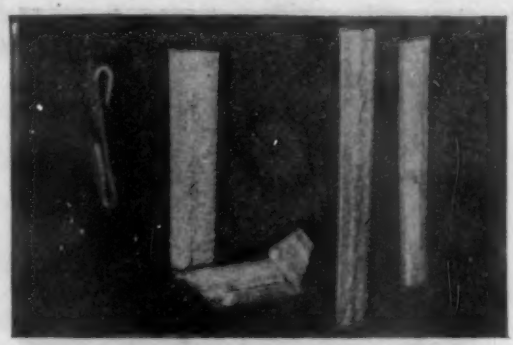


Fig. 17. Bending of Welded Samples

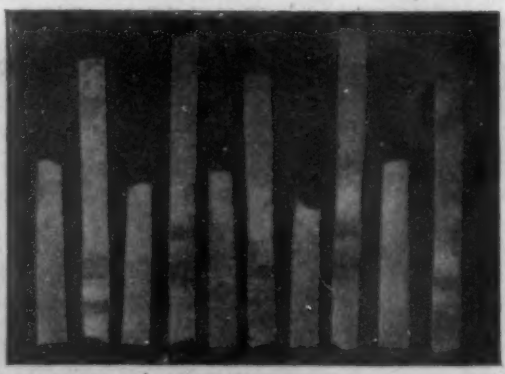


Fig. 18. Tension Test—Note That No Breaks Occurred at Welds

An average of 1 minute was taken for welding these specimens with 40 amp. and 60 volts across the arc. Tests for ductility were made on these specimens after being welded. They were bent transversely and longitudinally through 180 deg. without breaking in the welds.

Fig. 5 gives a microscopic section of the junction of the metal involved in the weld with the original parent metal. The enlarged grain boundaries due to the heat of the arc appear at the left side.

Fig. 6 shows three sides of a weld made with the material in

sheet form by full automatic control on the automatic machine using hydrogen with a 60-amp., 60-volt arc, at a speed of 30 in. per minute. The steels used for this experimental work on machine welding were mostly low carbon steels (0.10 to 0.20 C.), with thicknesses of 0.060 in. to 0.125 in., no material being added to the weld. Tests for ductility on these welds are shown in Figs. 16 and 17.

Up to the present time the automatic welding machine used in this process has not been fully developed, the greater part of the work being carried on with hand torches. In practically all the

Fig. 19. Material in Weld Rolled Into Ribbon

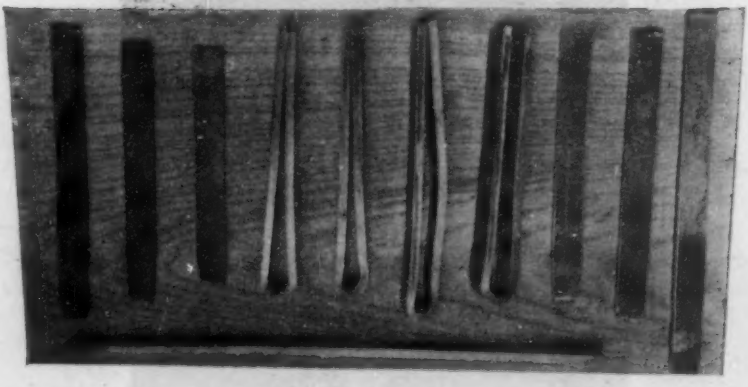


Fig. 20. Tension and Bending Tests on ¼-in. Cold-rolled Steel

illustrations to follow, unless especially mentioned, hand welding torches were used.

A number of welds were made on seamless tubing having a wall thickness of ¼ in. and an outside diameter of 4 in. to boiler plate iron 1 in. thick. The boiler plate was machined to permit the tube to project through to the opposite surface. The atomic hydrogen torch was applied at the junction of the tube and the boiler plate

directly over the place where they made contact with each other, fusing the two metals together to a depth of ⅜ in. and ½ in. wide. This weld completely surrounded the tube, making additional metal unnecessary, showing very little reduction of area if close fit is made for the tubes in the boiler plate.

Fig. 7 shows tubes made of low carbon steel 1 in. outside diameter, rolled from 1/64, 1/32, 1/16 and ⅛-in. sheet stock, butt welded on a mandrel. Tubes of the same dimensions and thickness of stock were made of high-content chromium steels, some of which are shown in Figs. 8 and 9. The latter shows glass seals attached to 25 per cent chromium steel for vacuum tests.

Welds on deoxidized copper such as silicon copper have been made up to ⅜ in. thick metal, giving unusually good sections.

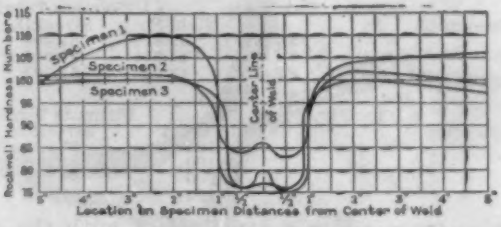


Fig. 21. Rockwell Hardness Tests on Hydrogen Arc Welds

Photographs of these welds were found to be too poor in detail for illustration. On short lengths of this copper, 2 in. by 4 in. by ⅜ in. thick, butt welds have been made by penetration from one side. With heavier pieces than this, welds were made on two sides or additional metal was added to the weld.

Fig. 10 shows a rectifier seal before and after the weld was made. The tubular part on the inside was made of 26 per cent chromium steel, the outer part of low carbon steel. Fig. 11 is a photomicrograph (100 diameters) showing a silicon copper and low carbon steel weld. Fig. 12 shows a silicon copper to invar (35 per cent Ni, 65 per cent Fe) seal weld, the invar is approximately 0.100 in. thick, the copper ⅛ in. thick. Fig. 13 shows a weld made between two pieces of low carbon steel with a filler rod containing 3 per cent tungsten, 1½ per cent chromium, 1.1 per cent vanadium and 0.60 per cent carbon.

Figs. 14, 15, 16, 17 show ductility tests on low carbon steels with thicknesses from 0.0625 to 0.375 in. In Fig. 14 a 45-deg. bevel was cut on each of two pieces of ⅜-in. thick cold rolled steel 12 in. long. A large bead was welded into the V formed by the two pieces. After welding it was placed in a hydraulic press and bent into an angle of 90 deg. as shown. Fig. 18 shows tensile tests made on ½-in. strips cut from one sheet, while Fig. 17 shows 180-deg. bends in both directions with respect to the weld.

Fig. 19 shows two strips of low carbon steel made from welds

cut out of sheet stock, the smaller a longitudinal weld 1/8 in. thick and 3/4 in. wide rolled hot to 1/64 in. thick; the larger strip is cut transversely from a sheet of seven welds made up of 1/4-in. stock 1 1/2 in. wide with ends butted together. In this rolled condition the weld has entirely disappeared. If the metal is properly annealed it can be used for sheet metal if desired.

Rockwell hardness tests using the diamond cone were made on strips of cold-rolled steel 3/4 in. wide and 14 in. long, these pieces being cut from sheets having butt welds in the center with a slight amount of Armco filler rod added (see Fig. 20). Ductility and tensile test were made at and near the welds. A typical curve showing the softest areas to be within 1/4 in. of the boundaries of the weld is given in Fig. 21, all bars tested breaking in this soft area.

TABLE I

Specimen	Width, In.	Thickness, In.	Yield Point	Ultimate Tensile Strength
1	0.775	0.2460	39,600	63,500
2	0.785	0.2485	45,300	67,000
3	0.784	0.2455	42,000	66,400

TABLE II

Specimen	Diameter, In.	Yield Point	Ultimate Tensile Strength
1	3/8	54,300	62,800
2	1/2	46,400	58,300
3	1/2	42,200	59,000
4	1/2	46,100	57,500

These samples were given a tensile test with the results shown in Table I. Test samples made of low carbon steel 0.20 C. with a double V weld, using Armco rod for filler gave tensile values according to Table II.

Arc Welding in Hydrogen and Other Gases

By P. ALEXANDER†

The growing importance of electric welding in manufacturing and structural work is constantly urging research engineers to pursue their work in improvements of methods and equipment with increasing energy. It is the purpose of this article to give a brief description of a new method of arc welding in a hydrogenated atmosphere.

The two problems that have attracted most attention in the last few years are greater speed of welding and improvement of ductility in the deposited metal. The first problem up to a certain limit can be solved by a continual increase in the welding current. The second is more difficult and is still in process of actual development. The reason for this is the exeptionally high temperature of the arc and the very short time in which chemical reactions and solidification of the metal are taking place.

The extensive research work carried out during the last decade by several laboratories and a number of isolated investigators has shown that the ductility of the weld is limited by the presence of

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†Thomson Research Laboratory, General Electric Company.

oxides and nitrides of iron introduced into the molten metal during the welding operation.

Aiming first at the solution of the second problem; that is, the production of more ductile welds, the author has been conducting a systematic investigation on welds produced in different gaseous media.

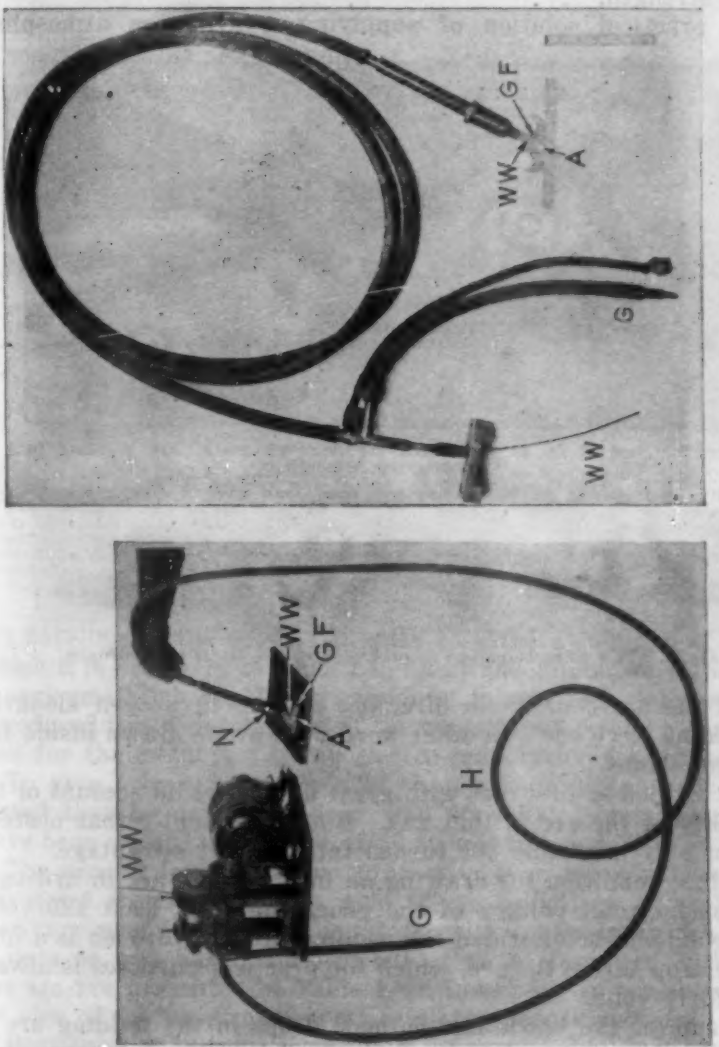

Fig. 1. Apparatus Used in Thomson Research Laboratory for Welding in a Hydrogenated Atmosphere with Metallic Electrode
A—Arc; G—Gas Hose; GF—Gas Flame; H—15-ft. Flexible Hose Conducting Gas, Electric Current, and Welding Wire; N—Nozzle; WW—Welding Wire.

Since the accepted explanation of brittleness in arc welds was the presence in the weld of oxides and nitrides of iron, the first experiments were conducted with the idea of complete elimination of both oxygen and nitrogen in the atmospheric gases around the arc.

The Hydrogen Weld

After a series of preliminary experiments with carbon dioxide, superheated steam, illuminating gas, and other gaseous mixtures, pure hydrogen was tried, which at once gave excellent results. The welds produced in that gas proved to be perfectly ductile, to be almost free from oxide inclusions, and to possess a very high tensile strength.

The practical solution of supplying a hydrogen atmosphere

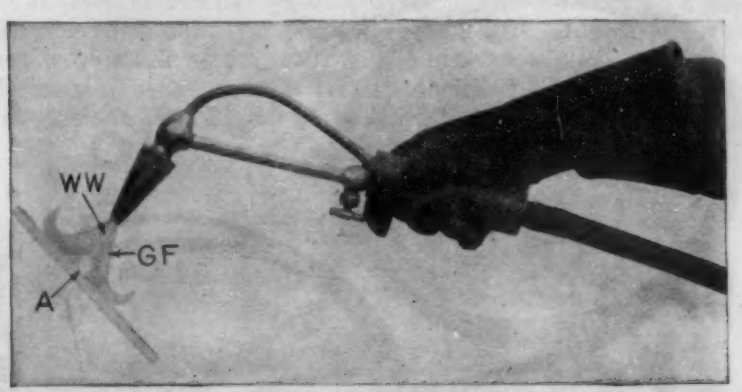

Fig. 2. New Model of the Torch for Semi-automatic Arc Welding in Hydrogenated Atmosphere
A—Arc; GF—Gas Flame; WW—Welding Wire.

Fig. 3. Test Bars Machined from Arc-deposited Metal in Hydrogen

around the arc consists in directing a jet of hydrogen alongside the welding electrode. In other words, the arc is drawn inside of a hydrogen flame.

This method at first met with great difficulties on account of the instability of the arc in that gas. But subsequently that obstacle was not only overcome but turned into a great advantage.

The first condition for drawing an iron welding arc in hydrogen is an open-circuit voltage of the generator of at least 120 volts. The second characteristic of the welding arc in hydrogen is a high voltage drop across the arc, which for practical purposes is always about forty volts.

The sum of the anode and cathode drops in the welding arc of 100 amperes was found to be about 30 volts, which is more than double that of the same arc in air.

From this it follows that with the same welding current the apparent double resistance of the arc permits the liberation in the arc of double amounts of energy.

This advantage has been utilized still further by using arcs of

55-60 volts. In that case the energy of the arc is trebled and is sufficient to do welding of the stock up to half an inch in thickness without beveling the edges of the plates. This in itself is a considerable saving in time and cost.

The average speed of welding attained with the apparatus shown in Fig. 1 on ¼-in. and ½-in plates was considerably higher than that attained in air even with slightly higher currents.

Speed

The high speed of the hydrogen weld is due to two causes—first a much greater energy of the arc and second to the welding with-

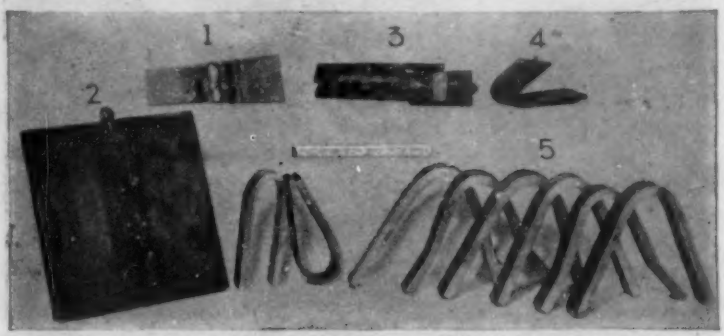

Fig. 4. Various Samples of Welds in Hydrogen
1—¼-in. stock with a very high bead and practically no penetration. (The other extreme is shown in specimen 2).
2—½-in. boiler plate welded with high-power arc. The welding is accomplished without beveling the edges of the plates.
3—Nickel-chromium alloy welded with carbon electrode.
4—Stainless steel welded with metallic electrode.
5—Test bars welded in the middle.

out beveling of the edges. In such case the amount of the metal which it is necessary to deposit to fill up the gap between the plates is very small indeed. The operation of joining two plates edgewise is reduced to a rapid melting of the edges together and a compensation for the metal lost by an electro-evaporation from the crater.

To give a specific example of the speed of welding, it can be stated that by using 180 amp. and 60 volts, ¼-in. boiler plates have been welded at a speed of 60 ft. per hr.

The second feature of the process is even more valuable than the speed, in that it gives a weld of great ductility. Fig. 3 shows test bars machined out of metal deposited entirely by the arc.

Data on test bars machined out of metal deposited entirely by the arc are presented in Table I, an inspection of which will give an idea of the physical properties of the deposited metal.

Particular attention is called to its remarkable ductility. This is a factor of prime importance in the welds of structures that are subjected to vibration, accidental bending stress, or overload. Also, it equalizes the internal cooling stresses when present in the weld.

If any part of the ductile weld is stressed beyond its elastic

limit, it will not crack. It will yield until the stresses are more or less equalized all along the joint, which is so proportioned as to stand with safety the imposed load.

As it was stated, the arc is maintained inside of a hydrogen stream which burns along its outer surface of contact with the air. The electrode is entirely surrounded by hydrogen, which eliminates the possibility of the metal in the crater coming in contact with air.

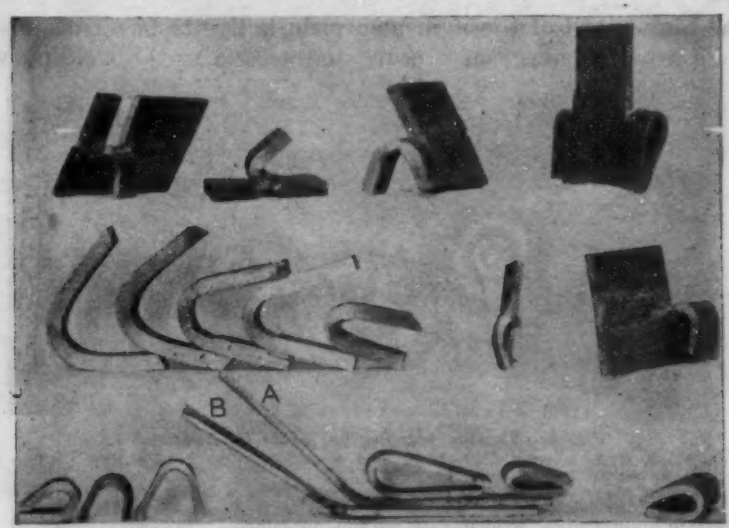

Fig. 5. A Variety of Test Pieces Welded with the Metallic Electrode in Hydrogen
A and B in bottom row—Test bars welded under identical conditions in air, maximum bend 30 deg.

TABLE 1

Material	Electrode Used	Carbon Content	Elastic Limit	Tensile Strength	Reduction of Area, Per Cent	Elongation, Per Cent
Arc deposited metal	Sheathed electrode	of the Deposited Metals 0.05	42,000	57,800	55	36
			39,375	55,435	49	31
			42,685	56,750	40	29.5

At high temperature hydrogen acts not only as a blanketing medium but also as one of the most energetic chemical reagents. Besides this action of molecular hydrogen a certain amount of the gas in the vicinity of the arc core is dissociated into the atomic state and its exceptional affinity for oxygen is sufficient to prevent any oxidation of the weld.

Neither the oxygen produced by the decomposition of oxides present in the metal plate nor that which infilters through the hydrogen flame will combine with iron so long as a sufficient amount of hydrogen is present.

The active nature of hydrogen is of paramount importance for practical applications of the process. As practically all arc welding is done in open air, it is impracticable to devise a torch which will absolutely exclude all the air from around the arc, and unless

hydrogen neutralizes the action of infiltrated oxygen and nitrogen the results cannot be uniform.

Summarizing the above brief description of the hydrogen process, it can be stated that it accomplishes two main purposes; first, it increases the speed of welding by concentrating in the arc large amounts of energy without the use of excessive currents; and second, it produces a perfectly ductile weld.

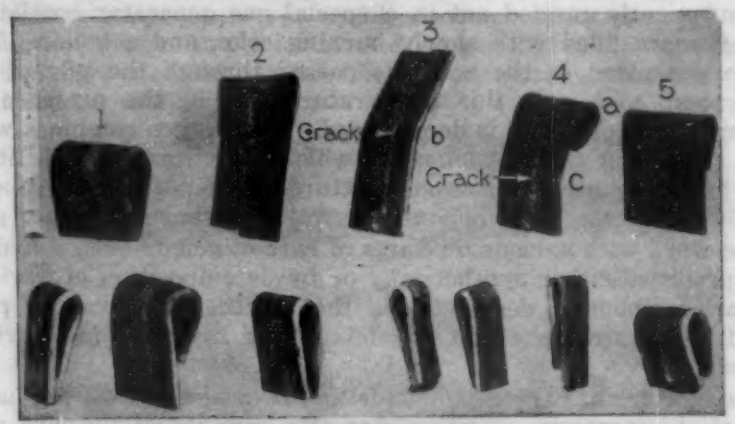

Fig. 6. Various Thin Stock Specimens Welded in Hydrogen and in Air, with Metallic and with Carbon Electrodes

Top Row—Metallic electrode: 1, 2 and 5 in hydrogen; 3 in air; 4 part a in hydrogen, part c in air. Bottom Row—Carbon electrode: all in hydrogen.

The continuous absorption and evolution of large amounts of hydrogen by the molten metal is equivalent to a thorough washing of the liquid metal with hot hydrogen. It is believed that the exceptionally high elastic limit of the deposited metal is due to this washing with atomic hydrogen. Indeed the elastic limit of the pure iron electrode before deposition is on an average 29,000 lb. per sq. in. The elastic limit of the same electrode deposited by the arc in hydrogen is on an average 42,000 lb. per sq. in.

Welding in Water Gas Atmosphere

After the work on the hydrogen welding had been found to be successful as stated, Professor Elihu Thomson suggested the great desirability of testing whether mixtures of gases containing hydrogen or substances which under the heat of the arc would produce hydrogen along with carbon monoxide would not give a thoroughly practical result, such as would meet the necessities of the ordinary art. One of the first of these tried was actually water gas, which is a mixture of equal volumes of carbon monoxide and hydrogen gas. It was established that a weld produced in water gas or certain other gaseous mixtures or mixtures of gases and vapors is perfectly ductile and easier to produce than when made in substantially pure hydrogen. It was found that the open circuit volt-

age of the welding generator need not be abnormally high and that the arc itself became much more stable. Other investigations were carried on with various mixtures in which the substantial composition of the resulting gases, when exposed to the heat of the arc, would be of the same nature as that of water gas. Another advantage of water gas is its exceedingly low price.

The usual method of generation of water gas is by passing a jet of steam over the surface of incandescent coke. This operation is conveniently carried out in a special gas generator consisting of a furnace filled with slowly burning coke, and a boiler. The steam generated in the boiler is passed through the pile of incandescent coke. At this temperature and in the presence of carbon, water or steam is decomposed. The oxygen combines with coke, producing carbon monoxide, which after mixing with liberated hydrogen gives a gaseous mixture of 50 per cent hydrogen and 50 per cent carbon monoxide by volume, known as water gas.

The work with various mixtures of carbon monoxide and hydrogen, produced either synthetically or by decomposition of various organic compounds, demonstrated that ductile welds can be produced in the atmosphere of any mixture of hydrogen and carbon monoxide.

The mixture of carbon monoxide and hydrogen can be produced in special generators or, as in case of a mixture of propane and carbon dioxide, immediately in the flame surrounding the arc.

Among all the gases and organic compounds, methanol deserves a special consideration. Methanol or synthetic wood alcohol, designated by a chemical formula CH_3OH, is a liquid at ordinary temperature. It boils at 66 deg. C. and the vapors are completely decomposed into hydrogen and carbon monoxide at about 700 deg. C.

This shows that a gaseous mixture of a similar composition to water gas can be stored in a perfectly stable liquid form. It can be easily transported with the portable welding outfits and, when desired, readily converted into a gaseous mixture. The significance of the storage of gases in a liquid state can be seen from the fact that one gallon of methanol will give 232 cu. ft. of gas.

Another great advantage of methanol is that carbon monoxide and hydrogen are stored in a chemically combined state, which eliminates any danger from poisonous action of the former gas, in case of a slight leakage from the storage container.

The decomposition of methanol vapor into a mixture of hydrogen and carbon monoxide can be effected in a special dissociation chamber or inside of the flame played from the nozzle of the welding torch. At the surface of the flame these gases combine with the oxygen of the air and, due to the excess of that gas, are completely converted into water vapor and carbon dioxide. The welding torches with metallic or carbon electrodes are the same as those used for welding in pure hydrogen.

Methanol is a cheap commercial product and the latest developments of producing it on a large scale indicate that in the very near future the welding in dissociated methanol will be almost as cheap as in water gas.

Welding in Nitrogen-Hydrogen Mixtures

The idea of welding in an atmosphere of neutral gases is not a new one. Carbon dioxide, which is an example, although neutral at ordinary temperatures, is readily decomposed by the high temperature of the arc into a mixture of oxygen and carbon monoxide, and therefore the weld produced in a CO_2 atmosphere is highly oxidized and is quite brittle.

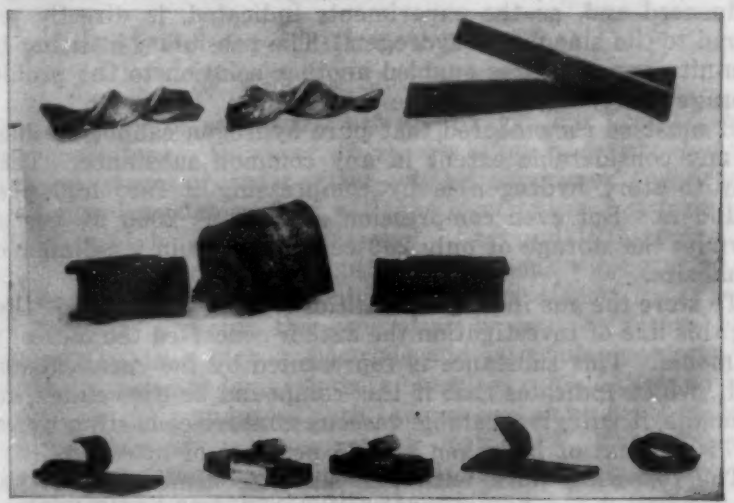

Fig. 7. Various Samples Twisted or Bent More Than 180 Deg. Without Cracking

Top Row—Twisting tests. Middle Row—Samples welded with carbon arc in hydrogen. Bottom Row—Bending tests on arc-deposited metal.

Welding in nitrogen has been tried by many investigators, and the results obtained were not at all encouraging. Lately the extensive work on nitrides in steel and electric welds demonstrated the deleterious effect of nitrogen at high temperatures on ferrous alloys.

These various investigations demonstrated without room for doubt that if the nitrogen content in steel reaches 0.05 of one per cent the metal is so brittle that it cannot be used in engineering structures. Mixtures of nitrogen with carbon monoxide have also been tried without success. It seemed that nitrogen was barred from any welding work on ferrous alloys. Yet Dr. Irving Langmuir and the author, after examination of all the evidence investigated once more the possibility of using this gas for welding, to ascertain whether some of the mixtures of this gas with various amounts of hydrogen could not be used for welding work.

A series of experiments conducted with the nitrogen-hydrogen mixtures demonstrated that mixtures of these gases give perfectly

ductile welds and that the amount of hydrogen might be varied within very wide limits. It might he as high as 90 and as low as 10 per cent. If the proportion of either gas exceeds 90 per cent the stability of the arc and the quality of the weld are characteristic of the predominating gas. By taking special precautions and by using gases of very high purity, the percentage of hydrogen may be reduced to 6 per cent or even less and still produce fairly ductile welds. Yet for practical purposes when the welding is done under factory conditions, 8 per cent of hydrogen should be regarded as the lower limit. The presence of nitrogen in the gaseous mixture is manifested by a much lower striking voltage and a greater stability of the arc. The arc voltage also is greatly influenced and, as the experiments indicated, is directly proportional to the amount of hydrogen. The possibility of using hydrogen-nitrogen mixtures enabled another solution to the problem of storage of welding gases to be worked out.

It must be remembered that pure hydrogen cannot be dissolved to any considerable extent in any common substance. The only way to store hydrogen is by compressing it into high-pressure cylinders. But even compression as high as 2000 lb. per sq. in. permits the storage of only 200 cu. ft. of gas in a cylinder of the usual size.

To store the gas in large quantities it must be liquefied. Following this line of investigation the author conceived the idea of using ammonia. This substance is represented by the chemical formula NH_3, which indicates that if this compound be dissociated into its elements, it will give a stable gaseous mixture consisting by volume of 75 per cent of hydrogen and 25 per cent of nitrogen.

The following work with this sustance demonstrated that the decomposition can be accomplished very conveniently in the presence of the usual catalysts at a temperature as low as 600 deg. C.

The apparatus used for welding in dissociated ammonia consists of the ordinary storage cylinder containing 50 or 100 lb. anhydrous liquefied ammonia and a dissociation chamber about 12 in long provided with the catalyst and a heating coil. Once ammonia has passed through the dissociation chamber, it is entirely decomposed into a perfectly stable mixture of hydrogen and nitrogen which may be used immediately in the welding torch or stored in a gasometer. This mixture can be used in the same way as pure hydrogen for welding with metallic or carbon electrodes.

The significance of using ammonia can be seen from the fact that a comparatively small cylinder of 50-lb. capacity will supply 2250 cu. ft. of gas. The larger cylinders of the size of low-pressure hydrogen cylinders used in the factories contain 100 lb. of liquid ammonia and will produce 4500 cu. ft. of gas.

The present cost of liquid ammonia is fifteen cents per pound, so that the cost of the gaseous mixture will be one-third of one cent per cu. ft., which compares very favorably with the cost of hydrogen sold in high pressure tanks at one cent per cu. ft.

Conclusion

In the outlined methods of welding and the obtaining of protective gaesous media for the operation, emphasis was laid of hydrogen, water gas, methanol and ammonia, since these gases are likely to find immediate industrial application on a large scale.

The welding in other media and mixtures has been also thoroughly investigated. The results of those experiments are of a somewhat more academic nature and will be published in a separate article devoted to the theoretical aspect of the welding in different gaseous media and the mechanism of nitrogenation of the arc-fused metal.

Electro-Gas Under-Water Cutting

By WILLIAM SCHENSTROM†

A combination of an electric arc and oxygen has been tried for cutting operations. However, these operations were above water. In the early stages of under-water cutting, experiments were made with an acetylene flame along with the electric arc, but tests indicated that acetylene was unnecessary. Around 1915-16 the first authentic electric underwater cutting operations were started and now have been developed to a high state of efficiency.

The method is simply the generating of heat by means of an electric arc using a carbon electrode and introducing oxygen into the heated area in order to make a chemical combination with the steel in the same manner as with the oxy-acetylene flame which is used in ordinary above-water cutting operations. The oxygen for under-water cutting is furnished from bottles such as are used ordinarily in oxy-acetylene cutting operations.

The torch itself consists of a non-conductive handle with a shield in front of it to protect the hand of the operator from the heat of the arc. In front of the shield is the holder of the electrode with connection for the lead wire. There is also the connection for the oxygen hose to be connected on to the torch. A flat carbon electrode, which has two holes longitudinally through its center, is used and set into the holder. The two holes in the electrodes are at their posterior end connected to the hose from the oxygen bottle by means of the special connection. The cable and hose are connected together in one conduit. These, with the life line and air hose, complete the diver's under-water equipment.

The electric current values are 400 amperes to 1000 amperes, at 90 volts to 100 volts, depending on the condition under which the work is being done. It is desirable to have an absolutely constant potential under varying loads.

The cutting action of this torch is somewhat as follows:

The diver strikes an arc by first touching the end of his carbon to that point of the object where he wants to start cutting, and

†Welding engineer.

then withdraws it until he has a long electric arc between the end of the electrode and the metal to be cut. The heat from the arc causes a globe of vapor to form around the arc, which is further increased when the oxygen flowing through the carbon is projected on to the surface of the melting steel. Apparent difficulties as a result of the conductivity of water are thereby eliminated. The arc is constantly keeping this bubble or blanket of steam intact while the oxygen blows out any molten metal from the cut. The result is a remarkably clean cut which looks more like a cut with an oxy-acetylene flame than that of an electric arc.

There are considerable difficulties connected with the operation of the under-water cutting torch. The diver has a lot of apparatus to handle, has to take awkward positions to get at the work, combined with a certain amount of danger. In the winter the diver can only work a very short time before he becomes chilled. In dirty harbor water, such as around New York, the visibility is practically nil. Special electric diving lamps have been designed to help the diver in working in muddy water and at great depths. These lamps throw a beam of light four times as powerful as the headlight of a locomotive. Because of the heavy, hard glass bulbs, it is possible to burn them without any protection in the water, but they cannot be burned above water as the intense heat of the concentrated tungsten filament would melt the glass in a few minutes. A large reflector is used to direct the light against the work. Under good conditions, that is clear water, the lamps throw a beam of light approximately 35 ft. to 40 ft. If the water is very dirty, the effect is that of a heavy fog which absorbs a great deal of illumination. The motion of the tides and the continual movement of the water make it practically impossible for the diver to hold a constant arc length.

Applications of the under-water arc are too manifold to enumerate, but a few will be given below:

When preparations were made to dig the numerous intake and outlet tunnels necessary to convey 800,000 gal. per minute of cooling water from the East River to the condensers of the Hudson Avenue Power Station of the Brooklyn Edison Company, a coffer dam of 58 lb. steel sheet piles was driven along the river front. It was decided to cut the sheet piles under water. The line of the desired cut was 35 ft. under water and 150 piles were cut at this depth to uncover the intake and outlet tunnels. As many as 11 piles were cut in one day by one operator in spite of the 6 or 7 knot current of the East River and the extreme cold.

Recently, while a steamer was docked at her pier in Hoboken, one of the 1⅛-in. mooring wires became fouled in one of the steamer's propellers. The propeller was turning over at the time and before the engines could be stopped many turns of wire became wrapped tightly around the propeller and the shaft tube.

At first efforts were made to clear this wire by slowly turning this propeller and pulling on the free end of the wire. As there

were many cross turns around the shaft this effort was unsuccessful.

An under-water cutting outfit was obtained and in three hours the job was completed, and the steamer was ready to go to sea. If this means of removing the wire had not been available, the steamer would have had to go into dry dock.

In connection with raising various sunken submarines and other vessels, under-water cutting has been of invaluable assistance. In December, 1921, the U. S. Submarine S-48 while on a trial trip sank in 70 ft. of water off Bridgeport harbor. Those in command of the vessel had the presence of mind to discharge the ballast from the bow until the bow was afloat and the crew was then rescued. The stern, however, was still fast on the bottom. The under-water cutting apparatus was employed to burn through the heavily ribbed cast steel cover over the motor room hatch. A circular cut was made in this cover releasing the central toggle bolt so that the hatch cover could be opened. The divers were thereupon able to enter the submarine and close the water tight doors. A special hatch cover was prepared through which there was a hole for a 4-in. suction which was connected to a submerged pump enabling the pumping and lifting of the submarine and its ultimate recovery. Submarines sunk in Philadelphia were cut up into 3 or 4 longitudinal slices and taken up piece-meal.

The results achieved with this method have been remarkable and the demand is increasing rapidly.

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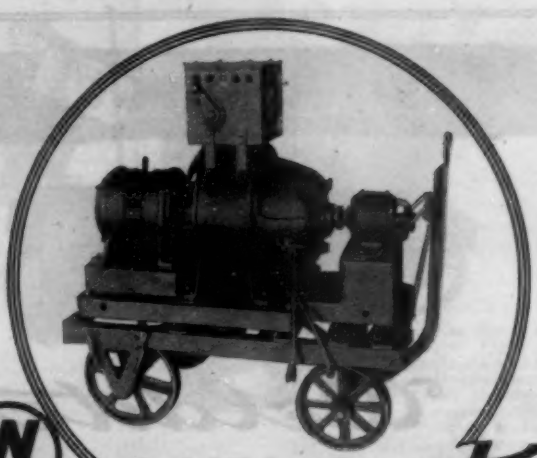

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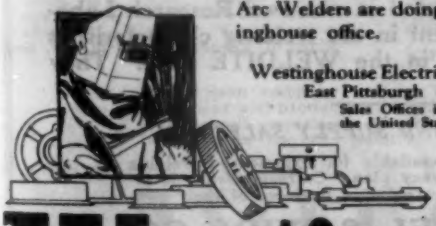
Why not get the complete facts, as demonstrated by actual welding work that the Westinghouse Portable Arc Welders are doing daily. Ask the nearest Westinghouse office.



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Welders like Wilson Wire because they know they can depend on its uniformity—they know it's always the same—that every rod is like every other rod of the same grade (analysis). And they know they can secure just the right grade for every type of welding job—each grade designated by a color. There is no saving in using inferior wire just because it's cheap. Use Wilson. Write today for samples of Wilson "Color-tipt" Welding Wire, indicating the metal you desire to weld.

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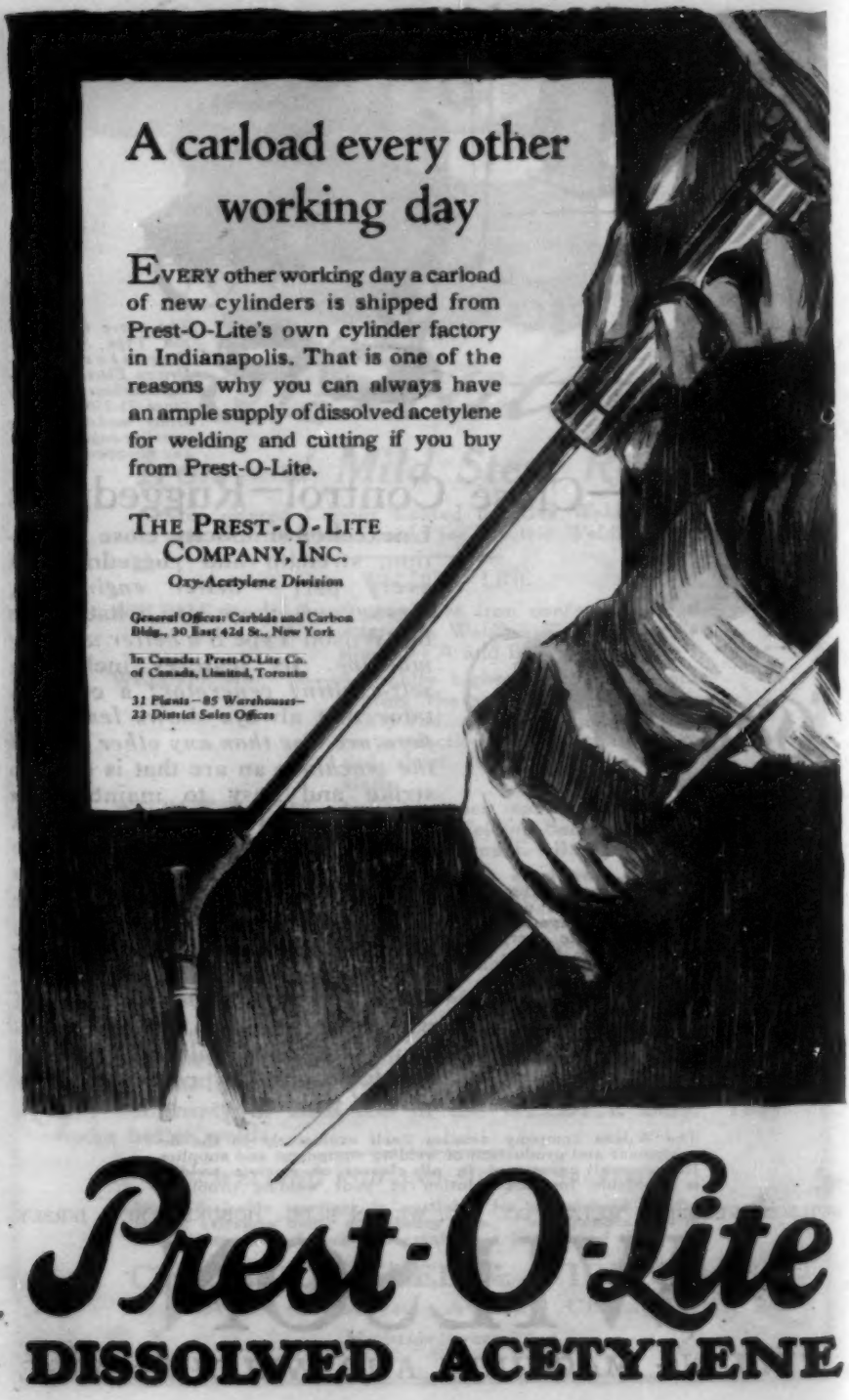
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This is the reason for Linde service. It starts with the product and its delivery to the customer It continues with service men of every rank, from practical welders to consulting engineers of wide experience, and with a research laboratory where new advances in the use of the oxy-acetylene process are perfected. It is even possible, with Linde Procedure Controls, for a customer to carry out difficult welding jobs unassisted.

LINDE Procedure controls for all types of pipe fabrication and line laying are available to customers. Our files contain many other Procedure Controls, such as fabrication of tanks, gear guards and steel pipe manifolds and reclamation of cast iron pulleys and pitted pipe. Special Procedure Controls will be prepared at the request of any Linde customer.

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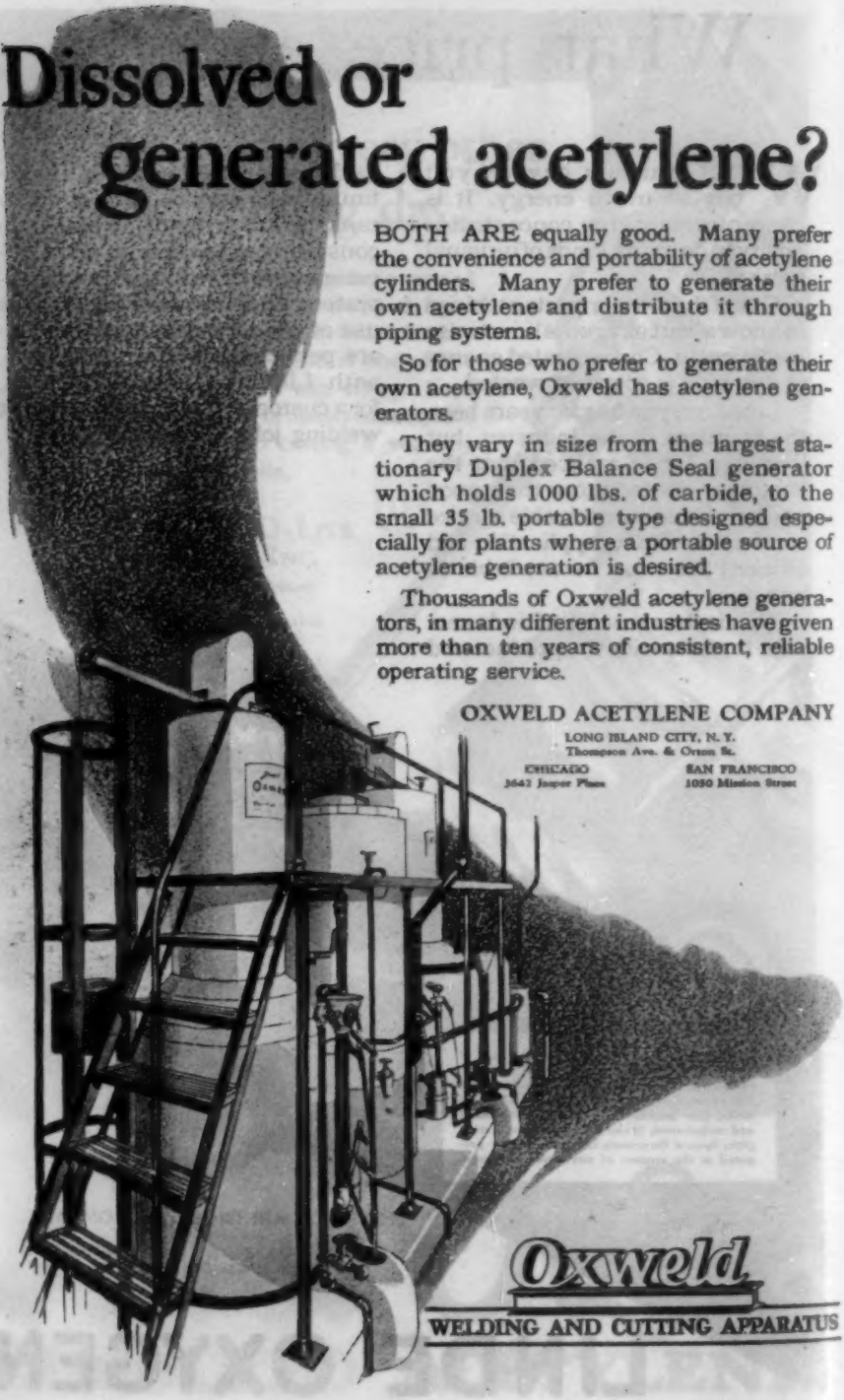
They vary in size from the largest stationary Duplex Balance Seal generator which holds 1000 lbs. of carbide, to the small 35 lb. portable type designed especially for plants where a portable source of acetylene generation is desired.

Thousands of Oxweld acetylene generators, in many different industries have given more than ten years of consistent, reliable operating service.



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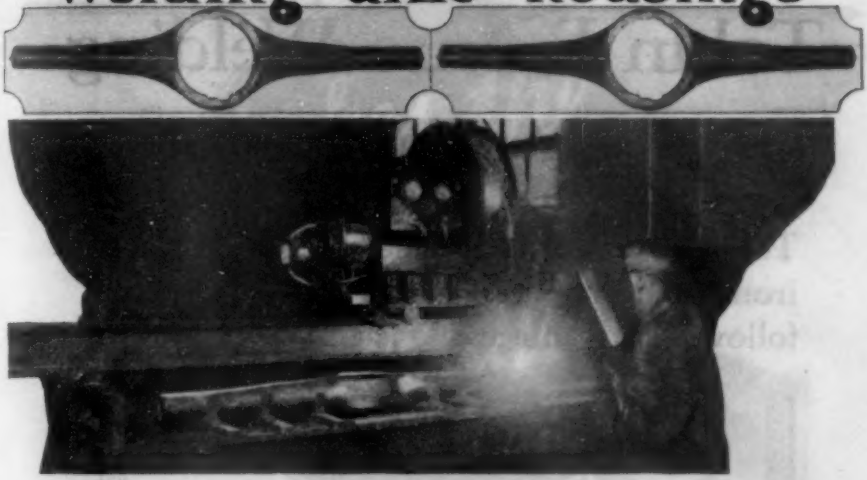
WELDING AND CUTTING APPARATUS

Welding axle housings



with G-E Automatic Welders

Every manufacturer of automobiles should be aware of the tremendous savings that are being effected by the automatic arc welding of axle housings.

A number of progressive manufacturers have installed G-E Automatic Arc Welders on this work because these machines have made it possible for them to have absolute control over both quantity and quality of product at all times. Results:

Production is doubled
Costs are decreased
Joints are strong and tight
Product is uniform and better

Because of the keen competition in the automotive field, the problem of reducing production costs is taxing the ingenuity of every manufacturer. Automatic welding not only of axle housings but of other automobile parts offers the manufacturer an exceptional opportunity to reduce production costs and to improve the quality of the product.

In addition to a complete line of arc welders of both manual and automatic operation, General Electric manufactures welding electrode wire. This wire is being used in the welding pictured above. The exceptional welds obtained from this wire and the very fast production made possible by its use are bringing it into general adoption everywhere.

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The base metal need only be heated to a dull red as Tobin Bronze flows freely at 1650° F.

This low welding temperature eliminates special pre-heating and often makes dismantling unnecessary.

Shrinkage can be prevented and the original alignment of broken parts retained.

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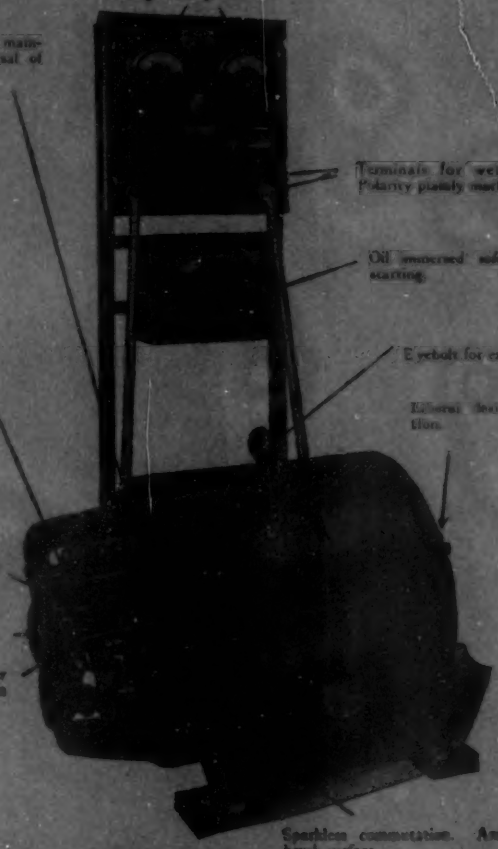
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